ACIL ALLEN CONSULTING

REPORT TO
NSW ENVIRONMENT PROTECTION AUTHORITY

SEPTEMBER 2014

LOAD-BASED LICENCE FEE COMPARISON

COMPARISON OF LOAD-BASED LICENCE FEES WITH MARGINAL ABATEMENT COSTS (MAC) AND MARGINAL EXTERNAL COSTS (MEC) FOR SELECTED POLLUTANTS

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Executive Summary

The NSW Environmental Protection Authority (NSW EPA) has engaged ACIL Allen Consulting and Pacific Environment Limited (PEL) to compare the Marginal Abatement Costs (MAC), Marginal External Cost (MEC) with Load Based Licence Fees (LBL) for selected pollutants. The LBL fee is a mechanism that links licence costs to type of pollutant, emissions load and zone. The results of this study will provide input into a review of the LBL scheme and in particular, a discussion paper that will be circulated for public consultation.

The study involved:

- The collation of abatement cost estimates for selected pollutants and adjustments to account for differences in study methods so that they could be compared;
- The collation of external cost estimates for selected pollutants;
- Comparison of abatement and external cost estimates with LBL fees; and
- Assignment of abatement cost and external cost estimates to corresponding LBL critical zones where possible.

The study included pollutants where literature sources were readily available that allowed comparison across the three measures (MAC, MEC and LBL). These were Particulate Matter (PM) (including $PM_{2.5}$, PM_{10} and PM with diameter greater than 10 µm), nitrogen oxides (NO_X), volatile organic compounds (VOCs), nitrogen emissions to water and phosphorus emissions to water. Two case studies (an air pollution abatement and a water pollution abatement) were undertaken to provide examples of current opportunities.

Results of the comparison indicate the extent to which LBL fees currently act as an incentive for abatement and whether any pollution reduction would generate benefits to the community that exceed costs of abatement.

While further study would need to be undertaken to verify, expand and improve the precision of estimates of MAC and MEC, and to assess the scope for adoption of abatement measures in NSW, there appear to be opportunities for low cost abatement that could lead to economic gains that are not currently being incentivised by the level of the LBL fee. This is particularly apparent for fine particulate matter, nitrogen emissions to water and phosphorus emission to water.

Comparison of Load-based licence fees with Marginal Abatement Costs (MAC) and Marginal External Costs (MEC) for Selected Pollutants

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1 Introduction

1.1 Background to study

The EPA is currently undertaking a wide ranging review of the Load Based Licensing (LBL) scheme. The aim of the review is to improve the effectiveness of the LBL scheme in driving reductions in air and water pollutant emissions, improve the efficiency and ease of use of the scheme for licensees and for the EPA, and ensure the scheme has a range of tools that can be used to respond to emerging pollution related issues.

The purpose of the study was to compare the current levels of LBL fees with corresponding estimates of abatement and externality costs. The outcomes of the study will be used in a discussion paper that will be circulated for public consultation.

The comparison of fee levels with abatement cost estimates indicates the extent to which the fee acts as an incentive to reduce pollutant emissions. The comparison of fee levels with externality cost estimates, indicates the extent to which the LBL reflects a 'Pigovian tax'[1], and encourages pollution reduction measures which provide net benefits to society.

1.2 Overview of Scheme

The LBL scheme was first introduced in 1999 and applies the 'polluter pays' principle. It is a mechanism to control, reduce and prevent air and water pollution in NSW. The fee regulations are outlined in the Protection of the Environment Operations (General) Regulation 2009 (POEO Regulation) and the Protection of the Environment Operations Act 1997 (POEO Act).

The scheme includes an administrative fee component (paid by all licensees based on the type and size of activity), a load based fee component (discussed below) and a fee rate threshold that results in a doubling of the load based fee for emissions beyond this threshold (set at a level that can be reasonably achieved with modern technology).

The load based fee component that applies to a particular facility is given by a formula that incorporates a:

- fee unit (increased annually) specified in Division 3 of the POEO Regulation;
- weighting for each pollutant;
- weighting based on the zone from which the pollutant is emitted;
- weighted based on the type of receiving waterway for water pollutants; and a
- design that results in summer emissions of NO_X and VOCs in the Sydney basin to be counted twice.

[1] A Pigovian tax works by setting charges for externalities (e.g. pollution) at the level of their expected damage to third parties.

The load based fee component is the focus of the study and the administrative fee, fee rate threshold and the effective fee from exceeding this threshold have not been considered.

The covered pollutants and industry activities that have obligations under the scheme are outlined in Schedule 1 of the POEO Act.

The mathematical form of the formula for the load based component is provided below (BDA, 2014).

$$Load\ based\ fee = (Assessable\ Load\ \times Polutant\ Weighting \times Critical\ Zone\ Weighting\ \times Pollutant\ Fee\ Unit) \div 10{,}000$$

As part the transition to an LBL mechanism, the fee unit was initially ramped up from zero in 1999 to a fee unit of $35 in 2003 (Ancev & Betz, 2006). The current POEO Regulation provides for an escalation of the fee of 2.5% per year to 1st July 2018.

During the operation of the scheme a number of academic reviews, including Ancev & Betz (2006) and Ancev, et al. (2012), of the scheme's performance have been undertaken as well as a Regulatory Impact Statement (RIS) by NSW EPA (2013). The original study by Ancev & Betz and their updated study using a richer data set due to concerns over sample size in the originl study, found that the fee did not have a statistically significant effect on NO_X abatement (Ancev & Betz, 2006; Ancev, et al., 2012). The RIS recommended continued increase to the price per pollutant fee in order to maintain the level of the incentive in real terms.

BDA Group (2014) undertook a comparative review of load based licensing systems for the NSW EPA, which provided observations on key features that have affected such schemes' performances.

This current study is part of the review of the scheme being undertaken by the NSW EPA in 2014.

1.3 Study scope

1.3.1 Pollutants

The selection of pollutants to include in the comparison was based on:

- An initial list provided by the NSW EPA;
- The availability of estimates from the literature that would allow comparison of abatement costs, damage estimates and LBL fees; and was
- Limited in scope reflecting time and budgetary constraints.

The pollutants covered by the study include:

- Particulate Matter (PM) of <=10μm in diameter[2], including $PM_{2.5}$ and PM_{10};
- 'Coarse' PM, defined as PM >10μm in diameter;
- Nitrogen oxides (NO_X);

2 Estimates relating to $PM_{2.5}$ and PM_{10} were compared with the fees applying to 'fine' particles. This is because the definition of 'fine' particles in the POEO Regulation covers both of these particle sizes. This is a somewhat uncommon definition, as 'fine' is generally used to refer $PM_{2.5}$ only.

- Volatile organic compounds (VOCs);
- Nitrogen emissions to water; and
- Phosphorus emissions to water.

1.3.2 Emissions sources

The collation of abatement cost estimates from the literature focussed on industrial sources of pollutant emissions, reflecting the activities covered by the LBL scheme. The POEO Act specifies which activities are covered and the emissions thresholds that apply. In doing so, it establishes which industrial activities are liable to pay LBL fees and which are effectively exempt. In the collation of abatement measures in this study, a test of whether the activity would in fact be liable under the LBL scheme was not performed. The rationale for this was to provide a broader set of abatement measures which could be considered by the NSW EPA as part of its review.

For water pollutants, abatement measures for non-industrial diffuse sources of emissions were also included in the study, on the basis that the scheme contains provisions for pollution offsets and literature has identified viable diffuse source opportunities (BDA Group, 2006).

1.3.3 Literature gaps identified

Recent studies have developed Australian damage cost functions for PM and NO_X, based on reviews of international studies and adjusting for Australian conditions (PAE Holmes, 2013; Boulter & Kulkarni, 2013). This work has to some extent addressed the gap in Australian estimates of damage costs identified in previous studies (ATSE, 2009).

Boulter & Kulkarni also provides assessments of the cost effectiveness of abatement measures that have been analysed as part of government regulatory processes (i.e. RIS and other studies). An additional study by SKM provided further cost estimates, however, the estimates were based largely on international studies and not adjusted for Australian conditions (SKM, 2010). The study notes that the estimates should be treated as indicative and not necessarily comparable across actions.

While we have found a range of estimates for water pollution abatement there appears to be very limited data on the external costs of water pollutants. For example, a number of non-market valuations studies (both stated and revealed preference) exist that estimate the external impacts of suspended solids and organic compounds. However, these are often expressed as the estimated willingness to pay (WTP) for improvements in water quality (e.g. concentration etc.) outcomes, as opposed to costs per tonne of emissions. Examples include:

- Um et al. (2002) estimated a WTP of between $0.07 and $1.70 (1998 US Dollars) for a 3% (10 mg/l) reduction in suspended solids using an averting behaviour method (ABM); and
- Poor et al. (2007) estimated a marginal implicit price for one milligram per litre change in total suspended solid at $1,086 (2003 US Dollars);

An international range estimate of the external costs of nitrogen and phosphorus was available from a study by BDA Group (2014). These pollutants were therefore included in the analysis. This estimate was derived using a range of values from other studies and the authors recognised that the estimates were subject to great uncertainty. The transferability of these estimates to NSW is limited given that the environmental conditions, ecology and profile of use of the receiving waterways is likely to be substantially different.

1.3.4 Limitations

While attempts were made to transform estimates from the literature so that they could be compared on an equivalent basis, simplifying assumptions were adopted for the purposes of these transformations and no detailed modelling was undertaken. Furthermore, no verification of abatement cost parameters has been undertaken.

Estimates applying to NSW were sought as a first preference, followed by estimates for Australia and lastly international estimates. The degree to which local and current estimates were available varied by pollutant. Factors which would need to be considered when judging the transferability of estimates to NSW are provided but an assessment of transferability was beyond the scope of this study.

The LBL fee varies by zone, receiving waterway (for water pollutants) and season (for NO_X and VOCs). Where it was appropriate, corresponding abatement or external cost estimates that would apply within the same zone were indicated. Otherwise, the estimates were not applied to corresponding zones and should be considered as representative estimates for the whole of NSW. Type of receiving waterways for water abatement measures were not identified as literature sources did not provide complete information on location of discharge(s).

2 Approach

2.1 Overview of Approach

The approach involved 3 key steps:

1. Compilation of LBL fees that would apply to a combination of pollutant, zone, receiving waterway and season, based on fee unit level for **2014/15**;
2. Collation of abatement and externality cost estimates;
3. Transformation of abatement and externality cost estimates to equivalent bases;
4. Allocation of abatement and externality cost estimates to corresponding zone, if appropriate, or whole of NSW, if otherwise.

The compilation of LBL fees was done by applying the LBL formula (without consideration of thresholds or the effective rate that would apply if threshold is exceeded). In doing so, for each combination of pollutant, zone, receiving waterway and season a fee unit was combined with an application of:

- Pollutant weight;
- Critical zone weight if applicable;
- Receiving waterway weight if applicable; and doubling of
- NO_X and VOC emissions during summer for the Sydney basin.

The collation of abatement and externality cost estimates was undertaken based on a desktop review of available literature. A summary of abatement measures is provided in Appendix A and a summary of literature sources for externality costs are provided in Appendix B.

The original study authors used a variety of methods to derive abatement and damage estimates. Although they may be expressed using the same unit (that is, dollars per tonne) the estimates are not always comparable. Section 2.2.2 outlines the steps used to transform estimates to facilitate comparison on equivalent bases. Abatement measures which had an extremely high cost of abatement were considered outliers and excluded from the analysis.

Estimates that applied to regions that appeared to have a high degree of overlap, or in some cases perfectly correspond with, critical zones as defined by the POEO were 'allocated' to the corresponding zone so that they could be compared with LBL fees that would apply to that same zone.

The results of this comparison are provided in Section 3.

2.2 Collation of Abatement Costs Estimates

2.2.1 Definition of Marginal Abatement Costs (MAC)

Marginal Abatement Costs (MAC) reflect the cost that a polluter would incur to abate an incremental tonne of pollutant. MACs provide a useful way to test whether an incentive mechanism such as the LBL, is effective. For example, a polluter that faces an LBL fee of $100 per tonne of pollutant and can reduce pollution through an abatement measure at a cost of $90 per tonne would implement that abatement measure and avoid paying the fee, all else equal. If the cost of abatement is higher than $100 per tonne, the polluter would choose not to adopt the abatement measure and instead pay the fee, all else equal. The costs in this instance, refer to the costs borne by the polluter or 'financial' costs. Costs that may be borne by other parties (such as government or third parties) as a result of the abatement measure being implemented should be excluded. While some of the measures were reported to have some government costs associated with implementation, costs have not been adjusted to compensate for this as these costs were insignificant in comparison to financial costs. Non-financial costs have however been considered in the conduct of the case studies.

Mathematically, MACs are calculated as aggregate incremental cost divided by aggregate incremental pollution reduction as shown below. However, methods used to perform this aggregation on both the numerator and denominator vary.

$$Marginal\ Abatement\ Costs = \frac{Aggregate\ incremental\ cost}{Aggregate\ incremental\ pollution\ reduction}$$

For the purposes of testing the effectiveness of fees as an incentive we consider the most appropriate method of calculating MACs to be the Equivalent Annual Cost (EAC) method (Boulter & Kulkarni, 2013). Application of this method will result in a more accurate simulation of a polluter's decision to implement an abatement measure because it takes into account the discount rate/cost of capital (e.g. interest rates) in both the calculation of aggregate costs ***and*** the calculation of aggregate benefits (avoided fees) of pollution reduction (i.e. both the numerator and denominator described in the equation above). The rationale and utility of the EAC method is further detailed in Section 2.2.2 below.

Another conceptual challenge faced in this study was the treatment of abatement measures that reduced multiple pollutants. In an economic or financial analysis, the calculation of marginal costs often involves a 'cost allocation' exercise. That is an identification of the portion of project costs attributable to the marginal outcome being sought. In estimates of pollutant MACs, it is almost always the case that 100% of project cost (net of non-pollutant benefits) is allocated to each pollutant being assessed. For example, a project that has an aggregate cost of $100 and abates 5 tonnes of PM and 10 tonnes of NO_X, will be calculated to have a MAC of $20 per tonne of PM and $10 per tonne of NO_X. While this is a simpler method that avoids a number of challenges faced when attempting cost allocation, it is not necessarily conducive to an assessment of the effectiveness of fees as an incentive to abatement. The approach used to allocate costs is further detailed in Section 2.2.2 below.

Other, less complex, facets of the transformation, notably currency, discount rates and real (inflation-adjusted) prices are discussed below. Finally, a discussion on the assessment of applicability of abatement measures to NSW is provided.

2.2.2 Issues in Comparability and Adjustments Applied

Method used for aggregation of emissions reduction

The EAC method was considered to be the most appropriate calculation method for expressing abatement costs in this study. However, it should be noted that this method is not widely adopted in the literature, largely due to the convention of using an ***undiscounted emissions*** approach to estimate abatement costs. The undiscounted emissions method, applies a simple (undiscounted) sum to aggregate total emissions (the denominator of the above equation). To some extent, this method is both simpler and reflects the fact that whether the benefits of emissions reduction should be discounted (and using what discount rate) is a point of contention. However, for the purposes of this comparison exercise, the same discount rate for both costs and ***avoided costs*** (i.e. avoided fees through emissions reduction) is recommended. Therefore a transformation is required and outlined below.

The equation for the undiscounted emissions approach is provided below:

$$Cost\ of\ abatement\ (\$/t) = \frac{\sum_{i=1}^{n} \frac{Cost\ in\ year\ i}{(1+r)^i}}{\sum_{i=1}^{n} Emissions\ reduced\ in\ year\ i}$$

(Where r is the discount rate and n is the number of years in the timeframe for analysing the abatement measure.)

There are two ways that the EAC may be calculated. The first is to divide present value of cost by present value of emissions, as shown in the equation below.

$$Cost\ of\ abatement\ (\$/t) = \frac{\sum_{i=1}^{n} \frac{Cost\ in\ year\ i}{(1+r)^i}}{\sum_{i=1}^{n} \frac{Emissions\ reduction\ in\ year\ i}{(1+r)^i}}$$

A second simplified form (that assumes 1 year of capital expenditure and constant annual operating costs and emissions reduction) is to divide the annualised cost, by the annualised emissions reduction, as shown in the equation below[3].

$$Cost\ of\ abatement\ (\$/t) = \frac{C \times \frac{r}{1-(1+r)^{-n}} + O}{Annual\ emissions\ reduction}$$

(Where C is the assumed capital cost incurred in the first year of the project and O is the annual operating cost)

Conversion from a calculation adopting an undiscounted emissions approach to an EAC can be achieved by multiplying by the following factor (the mathematical proof is not provided here):

$$\frac{n}{\left(\frac{1-(1+r)^{-n}}{r}\right)}$$

(Note that in applying this factor, a constant annual emissions reduction is assumed).

[3] Unlike the preceding formulae, the one below does not apply discount rates to compute a present value calculation. Rather, annual costs (the *annualised* capital costs plus annual operating costs) are divided by annual emissions reductions.

This factor was applied in order to convert figures using different methods to an equivalent basis.

Abatement of Multiple Pollutants

Almost all estimates of MAC from the literature are calculated by allocating the total cost of the abatement measure to each pollutant being studied. This is a simple approach but in the case of an abatement measure targeting multiple pollutants and in the context of comparing abatement costs with LBL fees, it does not provide a useful way to assess whether the fee provides an incentive for abatement.

Hall (2012) noted that some abatement measures provide multiple pollutant reduction outcomes and therefore required an allocation procedure. This procedure would depend on the context of the study and the characteristics of the receiving water. A cost allocation procedure has already been undertaken in that study.

For other MAC estimates in this study, the following allocation approaches were considered:

1. 100% allocation to each pollutant – the convention;
2. A weighting based on the relative fee liability (fee rate multiplied by assessable load) faced by the licensee for each of the pollutants abated; or
3. An equal weighting (e.g. 50% each for a measure that reduces two pollutants, 33% for a measure that reduces three pollutants etc.)

The second approach above is ideal from the perspective of assessing fee incentives. That is, applying this approach results in an accurate simulation of the decision to abate based on a given level of fee. However, data, time and budget constraints prohibited this approach from being adopted.

While much less precise, the third approach provides a simple, albeit rough, approximation for a more precise cost allocation. The effect of applying this method (compared to an estimate derived using unadjusted figures from the literature) is summarised in Appendix E.

Adjustments to current Australia dollar prices

Some literature estimates of MAC were derived from international studies. All of the study authors provided the Australian dollar equivalents and these estimates were used, avoiding the need to perform any currency conversion. Estimates were inflated from the base year of the study to 2014 dollars using a compound average inflation rate of 2.5% (mid-range of the Reserve Bank of Australia inflation target band).

Adjustments to discount rate

In a financial analysis the discount rate reflects the opportunity cost of capital. MAC estimates from literature sources used two main discount rates (7% and 3%). The former is more consistent with the discount rate used by industry, therefore estimates using 3% were adjusted to estimate costs as if a 7% discount rate was used.

Availability of abatement opportunities in NSW

It was beyond the scope of this project to assess whether abatement opportunities reported in the literature are available (or feasible) in NSW, or to assess the potential emission reductions in NSW from these measures. Some information from the literature which may be useful in such an assessment is provided in the summary of abatement measures in Appendix A.

Some abatement measures have a MAC of lower than the applicable fee for emissions. In such cases, it is possible that the measures would have been considered or already implemented by polluters. However, this is not always going to be the case as there may be other factors inhibiting the uptake of measures such as lack of information, capital constraints or the technology/process not being suitable to conditions in NSW.

2.3 Collation of Externality Cost Estimates

2.3.1 Definition of Marginal External Costs (MEC)

Pollution is a form of externality whereby a third party is affected (incurs a cost) that is not borne by the polluter. The Marginal External Cost (MEC) is an estimate of the size of this 'external' cost (per incremental tonne of pollutant emitted).

External costs can include direct financial impacts to third parties, such as the impact to the aquaculture industry from pollution of waterways. They can also be non-financial, for example, the impact of pollution on recreation value of a waterway or the discomfort or illness caused by exposure to air pollution. Financial impacts are normally measured using market prices (for the affected goods or services), whereas 'non-market' valuation techniques are required for non-financial impacts.

MEC estimates seek to include the full economic (financial, environmental and social) costs of the externality. The MEC of pollutants can differ based on the location of emissions, the pressures faced by the receiving air-shed or waterway and the season. The structure of the LBL, through the application of weightings, reflects this fact.

MECs may be calculated using a 'damage cost' approach (which establishes the cost of pollution as a function of abatement, sometimes with the functional form and coefficients transferred from another jurisdiction) or the 'impact-pathway approach' (a more detailed approach which aims to trace the impact of incremental pollution based on resulting changes in pollution concentration, exposure and impact). Literature using both approaches were considered for this study.

2.3.2 Issues in Comparability and Adjustments Applied

Air pollution - Transferability to NSW

The Economic Analysis to Inform the National Plan for Clean Air (Boulter & Kulkarni, 2013) provided current and NSW area specific estimates for $PM_{2.5}$ and NO_X. The study used UK damage cost estimates (derived through full from impact pathway analysis) and adjusted for Australian conditions. A similar approach has been used in other Australian studies, with varying levels of adjustments, different underlying sources and much less spatial resolution. The context around each study is presented in Appendix B.

In some cases, estimates that apply to NSW or that correspond with critical LBL zones were available in the literature. For example, Boulter & Kulkarni (2013) provides estimates of the damage cost of $PM_{2.5}$ and NO_X for NSW, as well as certain Significant Urban Areas (SUA) (as defined by the Australian Bureau of Statistics (ABS)) in NSW. Otherwise, estimates were available for Australian or international damage costs.

The majority of the costs of air pollution relate to their impact on human health and in turn, a large proportion of these health costs relate to premature mortality (PAE Holmes, 2013). The costs are therefore affected by factors including but not limited to:

- Existing concentrations of pollution (e.g. VOCs externality costs are nonlinearly related to VOC emissions, so the state of the receiving environment is important);

- Population density of receiving air-shed; and
- Demography of receiving air-shed (age profile etc.).

It was beyond the scope of this study to assess the transferability of estimates, however these considerations should be taken into account when interpreting the study results and the context for these estimates are provided in Appendix B.

Water pollution - Transferability to NSW

An estimate of the MEC of pollution to water resources requires an assessment of how the services provided by the receiving water resource is affected by a change in water quality (Dr. Poder, et al., 2000). Services include 'withdrawal services' (such as use of water for agriculture or industrial processes), 'in-place services' (life support for plants and animals or use of recreation activities) and 'existence services' (reflecting concern for the environment etc.).

As with air pollutants, some of these impacts may be measured through market values (e.g. the economic impact to irrigated agriculture or aquaculture etc.) whereas other impacts require non-market valuation techniques (e.g. the recreation value lost due to degradation in water quality or impact on bio-diversity etc.).

Transferability of MEC estimates from other regions to NSW require consideration of:

- Comparability of the services provided by the receiving waterway;
- Comparability of existing water quality conditions and pollutant concentrations; and
- How an incremental change in water quality may affect the value of the services provided.

As with estimates of MEC for air pollutants, it was beyond the scope of this study to assess the transferability of estimates, however these considerations should be taken into account when interpreting the study results and the context for these estimates are provided in Appendix B.

Adjustments to current Australia dollar prices

Some literature estimates of MEC were derived from international studies. In most cases the study authors provided the Australian dollar equivalent and these estimates were used, avoiding the need to perform any currency conversion. In one case a US dollar conversion was required and published exchange rates from the Reserve Bank of Australia (RBA) were used[4]. Estimates were inflated from the base year of the study to 2014 dollars using a compound average inflation rate of 2.5% (mid-range of the Reserve Bank of Australia inflation target band).

2.4 Load based fees in NSW

2.4.1 Calculation of Fee

The comparable LBL fee on a dollars per tonne basis was calculated through partial application of the load based fee component formula outlined below.

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[4] http://www.rba.gov.au/statistics/historical-data.html, last accessed 27 August 2014

$$Load\ based\ fee = (Assessable\ Load \times Polutant\ Weighting \times Critical\ Zone\ Weighting \times Pollutant\ Fee\ Unit) \div 10{,}000$$

Specifically, the assessable load factor was removed (which provided a dollars per tonne figure as opposed to a total fee dollars figure that would be provided if the complete formula was used).

This calculation was conducted for each combination of pollutant weight and critical zone. The results of this calculation are provided in Section 3.

2.4.2 Pollutant weightings

Pollutant weights for study pollutants were obtained from Part 2 - Table 1 and 2 of the POEO Regulation (reproduced in Appendix C). These are summarised in Table 1 and Table 2 below.

Table 1 **Air pollutant weightings**

Air Pollutant	Description	Weighting
Coarse particulates	All solid particulates entrained in air but not including fine particulates as defined in this Table	18
Fine particulates	The fraction of all solid particulates entrained in air with an aerodynamic diameter smaller than 10 micrometres	125
Nitrogen oxides and nitrogen oxides (summer)	The sum of nitrogen oxide and nitrogen dioxide expressed as nitrogen dioxide equivalent	9
VOCs and VOCs (summer)	Defined in clause 3 (1) of the POEO Regulation	7

Note: The pollutants weights for nitrogen oxides and VOCs emissions during summer apply twice
Source: Part 2 Table 1 of POEO Regulation

Table 2 **Water pollutant weightings**

Water Pollutant	Definition	Open coastal waters	Estuarine waters	Enclosed waters
Total nitrogen	Total nitrogen calculated using the method prescribed in the Approved Methods Publication	6	12	23

Total phosphorus	Total phosphorus calculated using the method prescribed in the Approved Methods Publication	-	120	680

Source: Part 2 Table 2 of POEO Regulation

2.4.3 Critical zone weightings

Critical zone weights for study pollutants were obtained from Part 1 - Table 1 of the POEO Regulation (reproduced in Appendix D). These are summarised in Table 3 and Table 4 below.

Table 3 **Critical zone weightings for air pollutants**

Air Pollutant	Description	Weighting
Nitrogen oxides and VOCs	Local government areas in the Sydney basin area, Blue Mountains City, Kiama, Shellharbour City and Wollongong City	7
Nitrogen oxides and VOCs	Cessnock City, Gosford City, Lake Macquarie City, Maitland City, Muswellbrook, Newcastle City, Port Stephens, Singleton, Wollondilly, Wyong	2

Source: Part 1 Table 1 of POEO Regulation

Table 4 **Critical zone weightings for water pollutants**

Air Pollutant	Description	Weighting
Total phosphorus and total nitrogen	Benanee, Border Rivers, Bulloo River, Castlereagh, Condamine/Culgoa, Cooper Creek, Darling, Gwydir, Hawkesbury-Nepean, Lachlan, Lake Bancannia, Lake Frome, Macquarie River, Moonie, Murray Riverina, Murray (Lower), Murray (Upper), Murrumbidgee, Namoi, Paroo, Warrego	3

Source: Part 1 Table 2 of POEO Regulation

2.4.4 Summer emissions of NO_X and VOC

As per the POEO Regulation, summer emissions of NO_X and VOCs for the Sydney basin are effectively counted twice (once as part of annual emissions and once as part of summer emissions) in the calculation of LBL fees that would apply.

3 Results of Comparisons

3.1 Air pollutants

3.1.1 Particulate Matter < 10 µm in diameter ($PM_{2.5}$ and PM_{10})

The effects of airborne particulate matter (PM), particularly particles with a diameter of less than 2.5 µm ($PM_{2.5}$) dominate overall mortality impacts associated with air pollution (PAE Holmes, 2013). Health effects of exposure to particulate matter include premature mortality, respiratory disease and cardiovascular disease. PM from industrial sources results from processes involving either combustion (e.g. industrial activity, vehicle exhaust) or abrasion (e.g. road vehicle tyre wear) (Boulter & Kulkarni, 2013).

Estimates of the MAC of $PM_{2.5}$ and PM_{10} have been primarily drawn from Boulter & Kulkarni (2013) and SKM (2010). Estimates of MEC have been drawn from Boulter & Kulkarni, (2013), BDA Group (2014), ATSE (2009) and Colagiuri, et al. (2012). Estimates relating to both overall PM_{10}, as well as $PM_{2.5}$ (which is a subset of PM_{10}) were compared against fees applying to 'fine' particulate matter.

The comparison of MAC, MEC and LBL fees relating to $PM_{2.5}$ and PM_{10} is provided in Figure 1, Figure 2 and in Table 1 below. Note that a measure which reduces PM_{10} will also reduce $PM_{2.5}$. The MAC estimates below are based on cost per tonne of PM_{10}.

Figure 1 **MAC, MEC and LBL fees for $PM_{2.5}$ and PM_{10}**

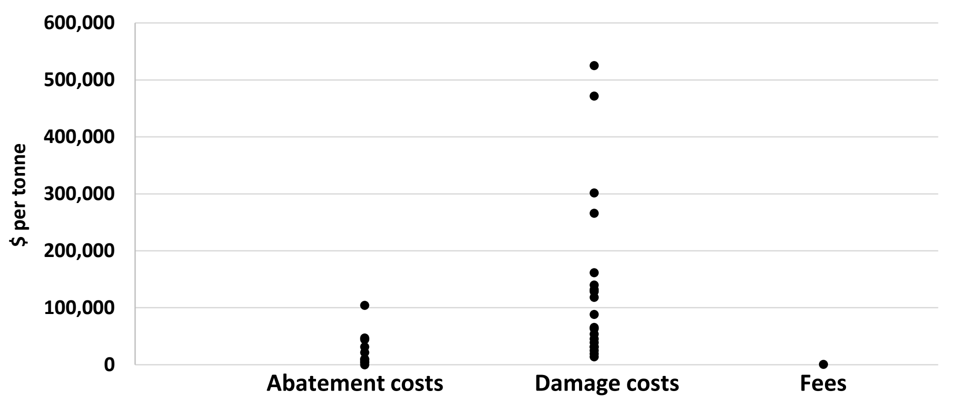


Figure 2 **MAC, MEC and LBL fees for $PM_{2.5}$ and PM_{10} (< 20,000 $/t)**

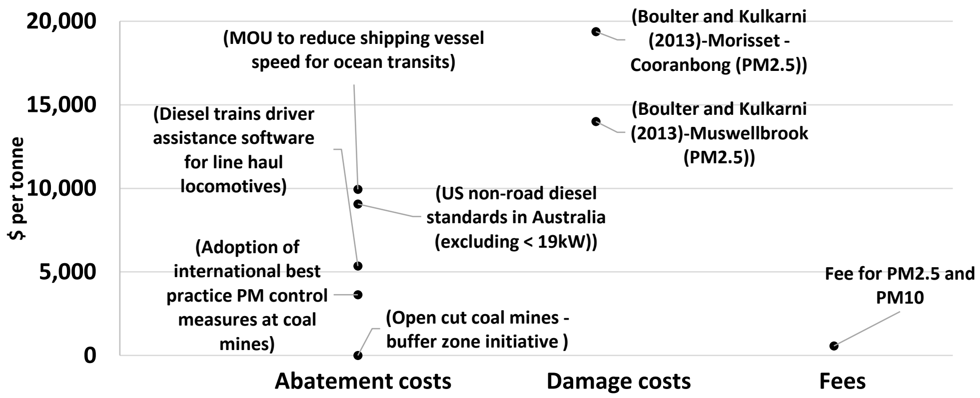


Table 5 **MAC, MEC and LBL fees for $PM_{2.5}$ and PM_{10}**

MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC)	Data on abatement (MAC) Context of estimate (MEC)
MAC	104,361	(Replacing old line locomotive and requiring new locomotives to meet US Tier 4)	143 tonnes per year in NSW
MAC	46,809	(Mandatory low sulfur fuel use by ships while at berth)	159 tonnes per year in NSW
MAC	44,281	(Retrofitting high-polluting (urban) diesel engines & equipment with DPFs)	7 tonnes per year in GMR
MAC	31,341	(Diesel retrofit at mine sites (ERP))	883 tonnes per year in NSW
MAC	21,296	(Requiring new locomotives to meet US Tier 4 standards)	69 tonnes per year in NSW
MAC	9,940	(MOU to reduce shipping vessel speed for ocean transits)	104 tonnes per year in NSW
MAC	9,062	(US non-road diesel standards in Australia (excluding < 19kW))	3,511 tonnes per year in NSW
MAC	5,350	(Diesel trains driver assistance software for line haul locomotives)	26 tonnes per year in NSW
MAC	3,637	(Adoption of international best practice PM control measures at coal mines)	39,874 tonnes per year in NSW

MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC)	Data on abatement (MAC) Context of estimate (MEC)
MAC	-	(Open cut coal mines - buffer zone initiative)	16,020 tonnes per year in GMR
MEC	525,313	(Colagiuiri, Cochrane and Girgis (2012)-High ($PM_{2.5}$))	Range for 407 US coal-fired power plants
MEC	471,880	(Watkiss (2002)-High (PM_{10}))	Derived from European 'ExternE' project, adjusted for population and applicable to inner areas of large capital cities (Melbourne, Sydney, Brisbane, Adelaide and Perth)
MEC	301,529	(Boulter and Kulkarni (2013)-Sydney ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	266,175	(DECCW (2010)-High (PM_{10}))	Average of earlier Australian damage cost estimates and applicable to capital cities
MEC	161,534	(Boulter and Kulkarni (2013)-Central Coast ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	139,996	(Boulter and Kulkarni (2013)-Wollongong ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	131,835	(ATSE (2009)-High (PM_{10}))	Derived from European 'ExternE' project , adjusted for relative population density around NSW power plants
MEC	128,705	(Watkiss (2002)-Low (PM_{10}))	Derived from European 'ExternE' project, adjusted for population and applicable to 'other urban areas' (Canberra, Hobart and Darwin)
MEC	118,458	(Boulter and Kulkarni (2013)-Newcastle - Maitland ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	88,305	(Boulter and Kulkarni (2013)-Cessnock ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	65,690	(Boulter and Kulkarni (2013)-Nelson Bay - Corlette ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)

MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC)	Data on abatement (MAC) Context of estimate (MEC)
MEC	63,161	(DECCW (2010)-Low (PM_{10}))	Average of earlier Australian damage cost estimates and applicable to areas other than capital cities
MEC	53,845	(Boulter and Kulkarni (2013)-Kurri Kurri - Weston ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	45,422	(ATSE (2009)-Low (PM_{10}))	Derived from European 'ExternE' project , adjusted for relative population density around NSW power plants
MEC	38,768	(Boulter and Kulkarni (2013)-Singleton ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	31,519	(Colagiuiri, Cochrane and Girgis (2012)-Low ($PM_{2.5}$))	Range for 407 US coal-fired power plants
MEC	31,230	(Boulter and Kulkarni (2013)-Lithgow ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	24,768	(Boulter and Kulkarni (2013)-Bowral - Mittagong ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	19,384	(Boulter and Kulkarni (2013)-Morisset - Cooranbong ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
MEC	14,000	(Boulter and Kulkarni (2013)-Muswellbrook ($PM_{2.5}$))	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
LBL Fee	574	Fee for $PM_{2.5}$ and PM_{10}	

Almost all estimates of abatement measure cost and all estimates of externality cost are higher than the level of the corresponding LBL fee. Notwithstanding the uncertainty surrounding some of these estimates and their scope for adoption in NSW, the results suggest that the fee is unlikely to incentivise significant abatement activity. Such abatement, if implemented, has the potential to reduce the external costs of $PM_{2.5}$ and PM_{10}. While the scale of the effect of PM_{10} emissions depends significantly on the density of exposed population, the LBL fee does not include any critical zone weightings for more densely populated areas.

3.1.2 Coarse particulate matter (particles larger than PM_{10})

Coarse particulate matter are defined in the POEO Regulation as *"all solid particulates entrained in air but not including fine particulates as defined"*, whereas fine particulates are defined as "*the fraction of all solid particulates entrained in air with an aerodynamic diameter smaller than 10 micrometres*". This definition is highlighted since the term *"coarse"* is often referred to in other literature as particulates with a diameter between 2 and 10 micrometres. There is stronger evidence of mortality and morbidity impacts associated with PM_{10} and in particular the finer fraction ($PM_{2.5}$). For example, Katestone Environment (2011) notes that coarse particulate matter (defined in their study as particles with diameters between 2.5 and 10 micrometres) may be expelled from the body by coughing or be swallowed as part of a the human body respiratory system's defence mechanism.

BDA Group, (2006) noted that particulates (red dust) from Whyalla in South Australia impacted on infrastructure and provided a quantitative estimate for 'Total PM' (excluding health costs associated with the fine particle fraction). This was used as a proxy estimate for the external impact of coarse particles.

This was compared to the estimated costs of reducing 'Total Suspended Particles' (TSP) using data points from the Katestone Environment study on coal mining best practice.

The resulting comparison of MAC, MEC and LBL fees relating to coarse PM is provided in Figure 3 and Table 1 below.

Figure 3 **MAC, MEC and LBL fees for coarse particular matter**

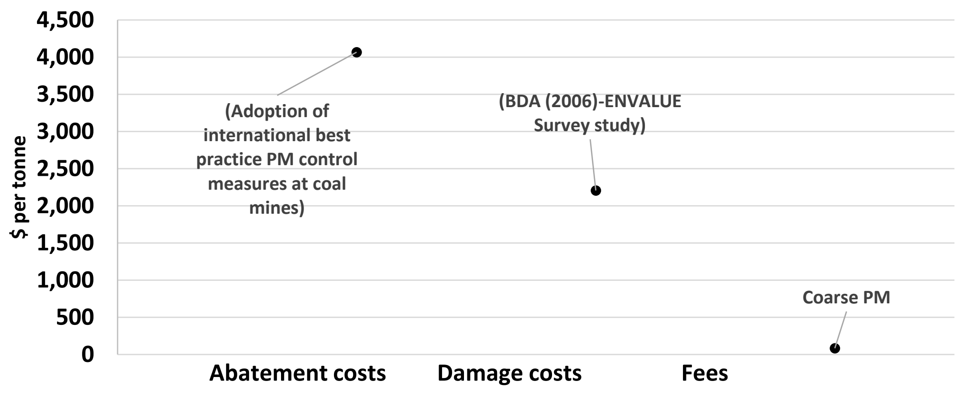


Table 6 **MAC, MEC and LBL fees for coarse particulate matter**

MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC)	Data on abatement (MAC) Context of estimate (MEC)
MAC	4,068	(Adoption of international best practice PM control measures at coal mines)	88,606 tonnes per year in GMR
MEC	2,205	(BDA (2006)-ENVALUE Survey study)	Survey study from ENVALUE database (no further context provided)

MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC)	Data on abatement (MAC) Context of estimate (MEC)
LBL Fee	83	Coarse PM	

Due to the limited data relating to abatement and external costs, it is not possible to make any strong conclusions based on the comparison, other than to note that LBL fees are lower than estimates found.

3.1.3 Nitrogen oxides (NO_X)

The health and environmental impacts of NO_X pollution include the direct and secondary effects (through the formation of secondary pollutants) on human health, impaired atmospheric visibility and the absorption of visible light, acidification and eutrophication and climate impacts Boulter & Kulkarni (2013). The effects are greater during summer as temperatures are more conducive to the formation of secondary pollutants. NO_X emissions from industrial sources are primarily a result of combustion processes.

Estimates of the MAC of NO_X have been primarily drawn from Boulter & Kulkarni (2013) and SKM, (2010). Estimates of MEC have been drawn from Boulter & Kulkarni (2013), BDA Group studies (BDA Group, 2006b; BDA Group 2014), ATSE (2009) and Colagiuri, et al., October (2012).

The comparison of MAC, MEC and LBL fees relating to NO_X is provided in Figure 4, Figure 5 and Table 7 below.

Figure 4 **MAC, MEC and LBL fees for NO_X**

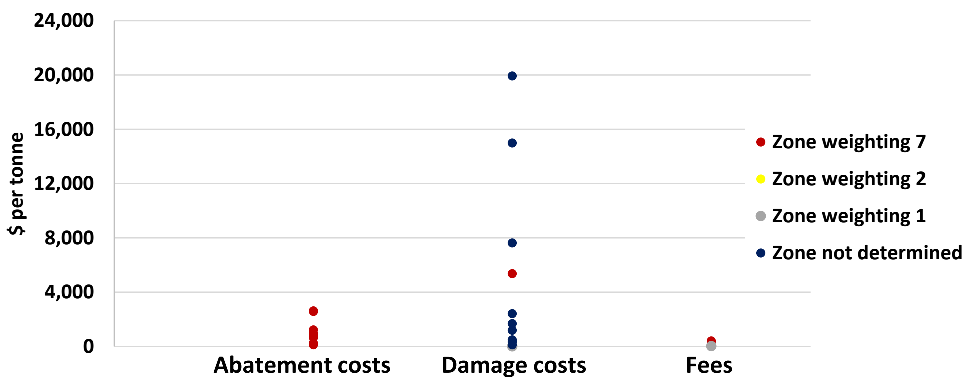


Figure 5 **MAC, MEC and LBL fees for NO_x (< 1,000 $/t)**

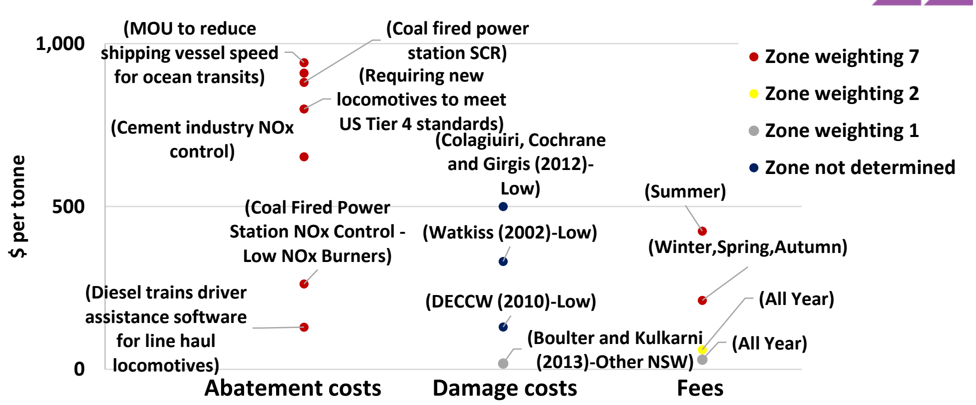


Table 7 **MAC, MEC and LBL fees for NO_x**

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone weighting 7	MAC	2,628	(Replacing old line locomotive and requiring new locomotives to meet US Tier 4)	5,854 tonnes per year
Zone weighting 7	MAC	2,580	(Adoption of SCR on gas reciprocating engines)	2,630 tonnes per year in GMR
Zone weighting 7	MAC	1,229	(US non-road diesel standards in Australia (excluding < 19kW))	26,700 tonnes per year
Zone weighting 7	MAC	942	(MOU to reduce shipping vessel speed for ocean transits)	1,193 tonnes per year
Zone weighting 7	MAC	910	(Adoption of lean burn on gas reciprocating engines)	not available
Zone weighting 7	MAC	881	(Coal fired power station SCR)	129,063 tonnes per year in GMR
Zone weighting 7	MAC	800	(Requiring new locomotives to meet US Tier 4 standards)	1,894 tonnes per year
Zone weighting 7	MAC	653	(Cement industry NOx control)	1,522 tonnes per year in GMR

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone weighting 7	MAC	263	(Coal Fired Power Station NOx Control - Low NOx Burners)	60,736 tonnes per year in GMR
Zone weighting 7	MAC	130	(Diesel trains driver assistance software for line haul locomotives)	1,107 tonnes per year
Zone not determined	MEC	19,941	(ATSE (2009)-High)	Derived from European 'ExternE' project, adjusted for relative population density around NSW power plants
Zone not determined	MEC	15,000	(Colagiuiri, Cochrane and Girgis (2012)-High)	Range for 407 US coal-fired power plants
Zone not determined	MEC	7,644	(ATSE (2009)-Low)	Derived from European 'ExternE' project, adjusted for relative population density around NSW power plants
Zone weighting 7	MEC	5,376	(Boulter and Kulkarni (2013)-Greater Sydney)	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
Zone not determined	MEC	2,428	(Watkiss (2002)-High)	Derived from European 'ExternE' project, adjusted for population and applicable to inner areas of large capital cities (Melbourne, Sydney, Brisbane, Adelaide and Perth)
Zone not determined	MEC	1,687	(BDA (2006)-ENVALUE Median NOx value from int. studies)	Median value from review of international studies (no further context provided)
Zone not determined	MEC	1,194	(DECCW (2010)-High)	Average of earlier Australian damage cost estimates and applicable to capital cities
Zone not determined	MEC	500	(Colagiuiri, Cochrane and Girgis (2012)-Low)	Range for 407 US coal-fired power plants
Zone not determined	MEC	331	(Watkiss (2002)-Low)	Derived from European 'ExternE' project, adjusted for population and applicable to 'other urban areas' (Canberra, Hobart and Darwin)

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone not determined	MEC	130	(DECCW (2010)-Low)	Average of earlier Australian damage cost estimates and applicable to areas other than capital cities
Zone weighting 1	MEC	18	(Boulter and Kulkarni (2013)-Other NSW)	Australian area-specific damage cost functions (UK functions adjusted for Australian conditions)
Zone weighting 7	LBL Fee	424	(Summer)	
Zone weighting 7	LBL Fee	212	(Winter,Spring,Autumn)	
Zone weighting 2	LBL Fee	61	(All Year)	
Zone weighting 1	LBL Fee	30	(All Year)	

Externality costs for densely populated areas are much higher than LBL fees that would apply in those zones. Only two of the abatement measures ('Coal Fired Power Station NO_X control' and 'Diesel trains driver assistance software for line haul locomotives') had an estimated MAC lower than corresponding LBL fees. Coal-fired power stations are already likely to be using low-NOx burners.

While lower estimates of damage cost are comparable with LBL fees, the estimate corresponding to the critical zone with weighting factor of 7 (Greater Sydney) is significantly higher than the corresponding LBL fee.

3.1.4 Volatile organic compounds (VOCs)

The effects of VOCs include short term respiratory health effects in susceptible populations, chronic disease, ozone formation, photochemical smog and nuisance odours (BDA Group, 2006b). VOC emissions from industrial sources include petroleum refineries, chemical industries and are associated with use of products such as paints, solvents and cleaners. There were fewer readily available estimates of MAC and MEC for VOCs. SKM (2010) provided three estimates for VOC reduction from industry. Estimates of MEC were obtained from studies by BDA Group (BDA Group, 2014; BDA Group, 2006b).

The comparison of MAC, MEC and LBL fees relating to VOCs is provided in Figure 6, Figure 7 and Table 1 below.

Figure 6 **MAC, MEC and LBL fees for VOCs**

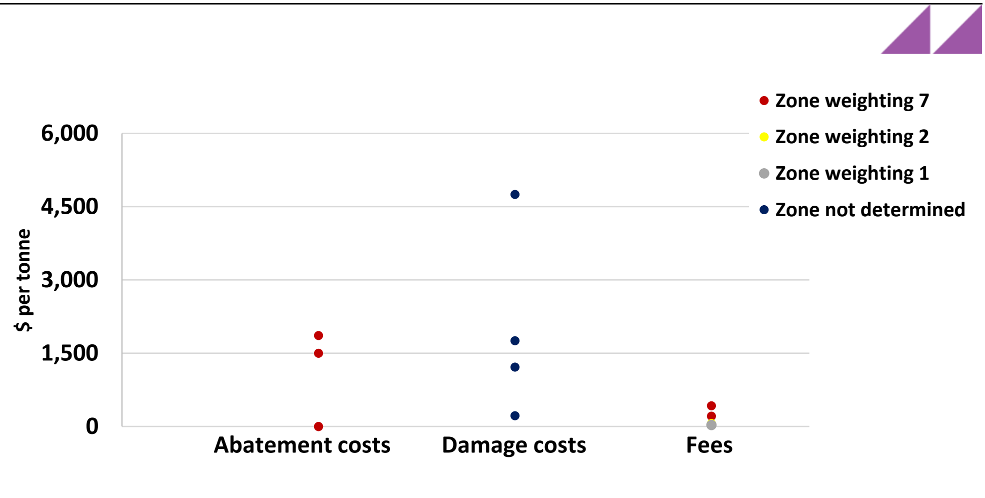


Figure 7 **MAC, MEC and LBL fees for VOCs (< 2,000 $/t)**

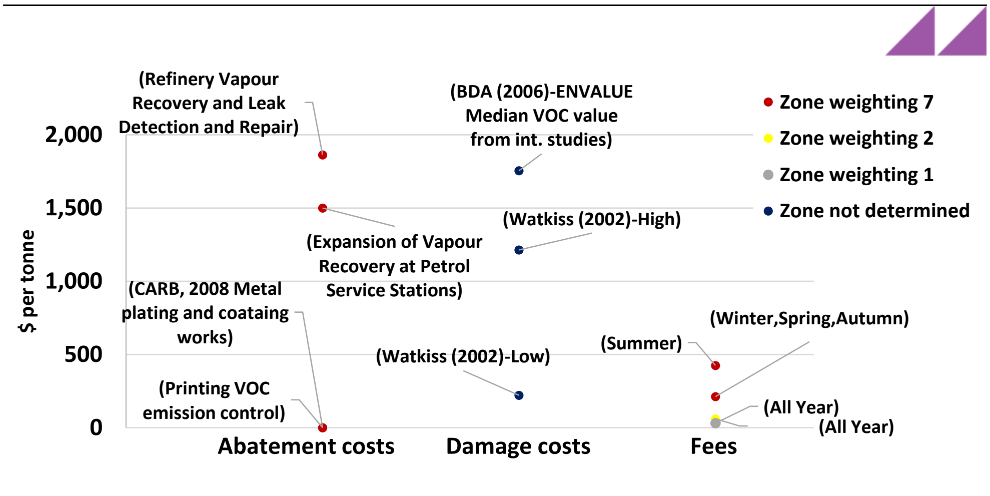


Table 8 **MAC, MEC and LBL fees for VOCs**

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone weighting 7	MAC	1,863	(Refinery Vapour Recovery and Leak Detection and Repair)	335 tonnes per year in GMR
Zone weighting 7	MAC	1,501	(Expansion of Vapour Recovery at Petrol Service Stations)	Approx. 7,000 tonnes per year in GMR

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone weighting 7	MAC	-	(CARB, 2008 Metal plating and coataing works)	1,068 tonnes per year in GMR
Zone weighting 7	MAC	-	(Printing VOC emission control)	2,172 tonnes per year in GMR
Zone not determined	MEC	4,752	(DECCW (2010)-Central)	Average of earlier Australian damage cost estimates
Zone not determined	MEC	1,755	(BDA (2006)-ENVALUE Median VOC value from int. studies)	Median value from review of international studies (no further context provided)
Zone not determined	MEC	1,214	(Watkiss (2002)-High)	Derived from European 'ExternE' project, adjusted for population and applicable to inner areas of large capital cities (Melbourne, Sydney, Brisbane, Adelaide and Perth)
Zone not determined	MEC	221	(Watkiss (2002)-Low)	Derived from European 'ExternE' project, adjusted for population and applicable to 'other urban areas' (Canberra, Hobart and Darwin)
Zone weighting 7	LBL Fee	424	(Summer)	
Zone weighting 7	LBL Fee	212	(Winter,Spring,Autumn)	
Zone weighting 2	LBL Fee	61	(All Year)	
Zone weighting 1	LBL Fee	30	(All Year)	

The majority of MEC estimates for VOC are higher than the level of the LBL fee. Estimates of MAC and MEC appear to be closer to LBL fees relative to other pollutants studied. However, this is based on estimates with a relatively high degree of uncertainty and somewhat out of date. For example, VOC reduction through refinery vapour recovery and leak detection and repair may not be an opportunity in NSW due to the closure of refineries but potential for VOC reduction from import terminals could be explored.

3.2 Water pollutants

3.2.1 Nitrogen

Both nitrogen and phosphorus can affect aquatic organisms by causing excessive plant growth which in turn depletes available oxygen levels (BDA Group, 2006b). In doing so, these nutrient discharges impact the diversity of aquatic life and can also reduce the value of recreation, commercial activities, irrigation and damage infrastructure. A range estimate for MEC of nitrogen was obtained from BDA Group (2014) and MAC estimates were obtained from BDA Group (2006) and Hall (2012).

The comparison of MAC, MEC and LBL fees relating to nitrogen is provided in Figure 8, Figure 9 and Table 9 below.

Figure 8 **MAC, MEC and LBL fees for nitrogen**

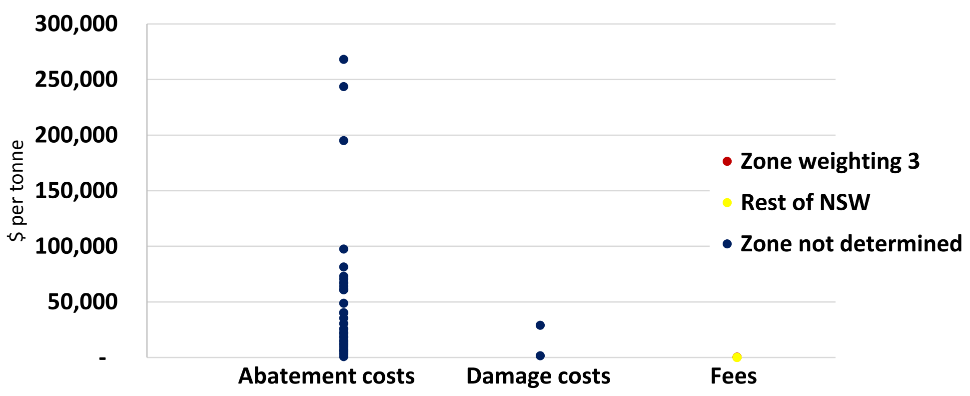
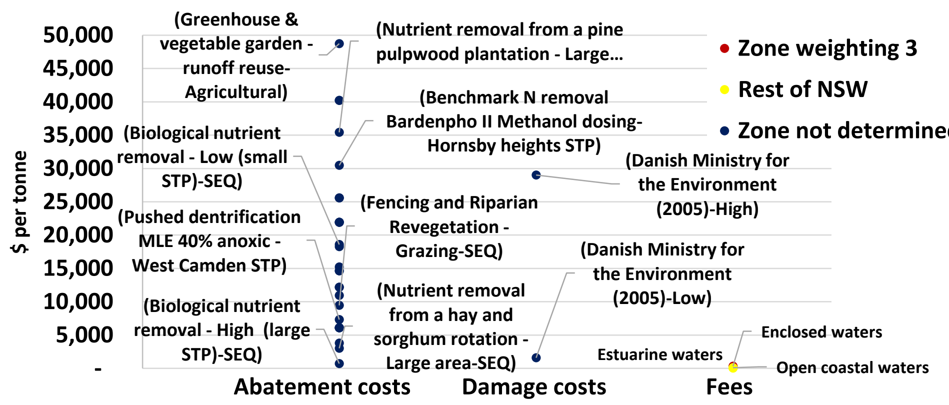


Figure 9 **MAC, MEC and LBL fees for nitrogen (< 50,000 $/t)**



Note: Labels not included for all points on chart to improve visibility

Table 9 **MAC, MEC and LBL fees for nitrogen**

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone not determined	MAC	268,049	(Fence/alternative water supply on grazing land-Agricultural)	not available
Zone not determined	MAC	243,681	(Better treatment at STPs - Port Waterways, SA -Urban)	not available
Zone not determined	MAC	195,139	(Tertiary filtration - Low (small STP)-SEQ)	Total 37 tonnes of nitrogen load reduction over 20 years in SEQ
Zone not determined	MAC	97,472	(Constructed wetlands - Port Phillip Bay, VIC-Urban)	not available
Zone not determined	MAC	81,309	(Tertiary filtration - High(large STP)-SEQ)	Total 2,190 tonnes of nitrogen load reduction over 20 years in SEQ
Zone not determined	MAC	73,104	(Constructed wetlands - Port Waterways, SA -Urban)	not available
Zone not determined	MAC	70,468	(Nutrient removal from a pine pulpwood plantation - Small area-SEQ)	0.08 tonnes per Ha per year (assuming 20 Ha) in SEQ
Zone not determined	MAC	67,012	(Best practice for cropping - Port Phillip Bay, VIC-Agricultural)	not available
Zone not determined	MAC	67,012	(Best practice for cropping - Port Phillip Bay, VIC-Agricultural)	not available
Zone not determined	MAC	63,966	(Compost study at market garden-Agricultural)	not available
Zone not determined	MAC	60,920	(Better treatment at STPs - Port Phillip Bay, VIC-Urban)	not available
Zone not determined	MAC	60,920	(Market garden - runoff reuse-Agricultural)	not available
Zone not determined	MAC	60,920	(Greenhouse - wetland and recycling-Agricultural)	not available
Zone not determined	MAC	48,736	(Greenhouse & vegetable garden - runoff reuse-Agricultural)	not available

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone not determined	MAC	40,207	(Benchmark N removal Bardenpho II Methanol dosing-North Richmond STP)	not available
Zone not determined	MAC	40,207	(Benchmark N removal Bardenpho II Methanol dosing-Richmond STP)	not available
Zone not determined	MAC	35,416	(Nutrient removal from a pine pulpwood plantation - Large area-SEQ)	0.08 tonnes per Ha per year (assuming 4,012 Ha) in SEQ
Zone not determined	MAC	30,460	(Benchmark N removal Bardenpho II Methanol dosing-Hornsby heights STP)	not available
Zone not determined	MAC	25,586	(Benchmark N removal Bardenpho II Methanol dosing-Rouse Hill STP)	not available
Zone not determined	MAC	25,586	(Benchmark N removal Bardenpho II Methanol dosing-West Hornsby STP)	not available
Zone not determined	MAC	21,931	(Benchmark N removal Bardenpho II Methanol dosing-St Marys STP)	not available
Zone not determined	MAC	21,931	(Benchmark N removal Bardenpho II Methanol dosing-Quakers Hill STP)	not available
Zone not determined	MAC	21,931	(Benchmark N removal Bardenpho II Methanol dosing-Riverstone STP)	not available
Zone not determined	MAC	18,584	(Biological nutrient removal - Low (small STP)-SEQ)	Total 75 tonnes of nitrogen load reduction over 20 years in SEQ
Zone not determined	MAC	18,276	(Buffer strips on horticultural land - South Creek, NSW (2002)-Agricultural)	not available
Zone not determined	MAC	15,230	(Market garden - settlement pond-Agricultural)	not available
Zone not determined	MAC	14,621	(Other point sources - Port Waterways, SA -Urban)	not available
Zone not determined	MAC	14,621	(Enhanced denitrification add fermentation-Wimmalee STP)	not available

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone not determined	MAC	12,184	(Constructed wetlands - South Creek, NSW (2002)-Urban)	not available
Zone not determined	MAC	12,184	(Riparian restoration - South Creek, NSW (2002)-Agricultural)	not available
Zone not determined	MAC	10,951	(Nutrient removal from a hay and sorghum rotation -Small area-SEQ)	0.517 tonnes per Ha per year (assuming 14 Ha) in SEQ
Zone not determined	MAC	9,461	(Fencing and Riparian Revegetation - Grazing-SEQ)	35 tonnes per/farm/20 years in SEQ
Zone not determined	MAC	7,310	(Pushed dentrification MLE 40% anoxic -West Camden STP)	not available
Zone not determined	MAC	6,092	(Modifying fertilizer use by horticulture - South Creek, NSW (2002)-Agricultural)	not available
Zone not determined	MAC	6,092	(Modifying fertilizer use by horticulture - Port Phillip Bay, VIC-Agricultural)	not available
Zone not determined	MAC	6,092	(Riparian restoration - Port Waterways, SA -Agricultural)	not available
Zone not determined	MAC	6,092	(Advanced denitrification MLE 40% anoxic-Castle Hill STP)	not available
Zone not determined	MAC	3,784	(Fencing and Riparian Revegetation - Intensive ag.-SEQ)	87 tonnes per/farm/20 years in SEQ
Zone not determined	MAC	3,021	(Nutrient removal from a hay and sorghum rotation - Large area-SEQ)	0.517 tonnes per Ha per year (assuming 2,793 Ha) in SEQ
Zone not determined	MAC	696	(Biological nutrient removal - High (large STP)-SEQ)	Total 7,470 tonnes of nitrogen load reduction over 20 years in SEQ
Zone not determined	MEC	29,000	(Danish Ministry for the Environment (2005)-High)	International literature study, contexts unknown
Zone not determined	MEC	1,600	(Danish Ministry for the Environment (2005)-Low)	International literature study, contexts unknown

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Season (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone weighting 3	LBL Fee	317	Enclosed waters	
Zone weighting 3	LBL Fee	165	Estuarine waters	
Rest of NSW	LBL Fee	106	Enclosed waters	
Zone weighting 3	LBL Fee	83	Open coastal waters	
Rest of NSW	LBL Fee	55	Estuarine waters	
Rest of NSW	LBL Fee	28	Open coastal waters	

Several abatement measures' MAC estimates fall within the range of high and low estimate for MEC. Both MAC and MEC estimates are mostly of an order of magnitude greater than the level of the LBL fee. Therefore, there may be opportunities to assess whether potential increases in the LBL fee could lead to external benefits that outweigh abatement costs.

However, two major qualifications should be noted. Firstly, the estimates of MEC are derived from a single international study. The environmental conditions, ecology and profile of use of the receiving waterways is likely to be substantially different. For example, the upper bound for nitrogen and lower bound for phosphorus used by the Danish Ministry for the Environment (2005), were derived from a 'Swedish-Polish' stated preference willingness to pay (WTP) study relating to discharges to the Baltic Sea.

Secondly, many of the low cost abatement measures may have already been adopted, or may be being developed, by licensees in NSW. For example, significant abatement efforts have been implemented over the last two decades at sewage treatment plants (STPs) in NSW. Sydney Water STPs operate at a treatment level ranging from primary to tertiary level treatment[5]. Wastewater treatment typically involves three stages: 'primary', 'secondary' and 'tertiary'. At the primary stage the wastewater is held in a basin in which heavy solids settle to the bottom and oils and lighter solids float to the surface. The settled and floating materials are then removed. Secondary treatment involves the removal of dissolved and suspended biological matter, and is typically performed by water-borne micro-organisms. After the primary and secondary stages the remaining liquid may be discharged or subjected to further treatment. Tertiary treatment is considered to be any further treatment that is applied so that water can be released into a highly sensitive or fragile ecosystem. This sometimes involves chemical or physical disinfection.

It should be noted that several of the abatement measures listed in Tables 9 and 10 will already have been implemented to a greater or lesser degree in NSW. The existing level of

[5] http://www.sydneywater.com.au/SW/water-the-environment/how-we-manage-sydney-s-water/wastewater-network/wastewater-treatment-plants/index.htm

treatment therefore needs to be borne in mind when considering the costs and benefits of further action.

3.2.2 Phosphorus

Both nitrogen and phosphorus can affect aquatic organisms by causing excessive plant growth which in turn depletes available oxygen levels BDA Group, (2006). In doing so, these nutrient discharges impact the diversity of aquatic life and can also reduce the value of recreation, commercial activities, irrigation and damage infrastructure. A range estimate for MEC of nitrogen was obtained from BDA Group (2014) and MAC estimates were obtained from BDA Group (2006) and Hall (2012).

The comparison of MAC, MEC and LBL fees relating to phosphorus is provided in Figure 10, Figure 11 and Table 10 below.

Figure 10 **MAC, MEC and LBL fees for phosphorus**

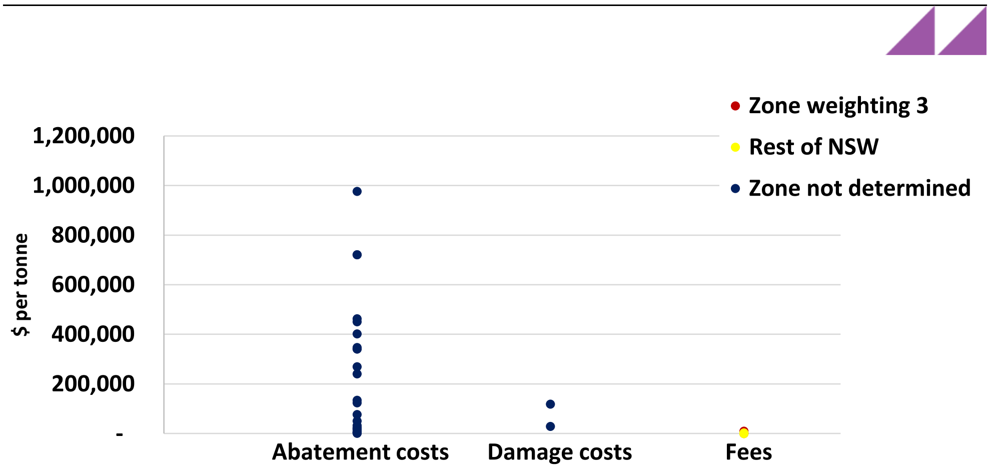
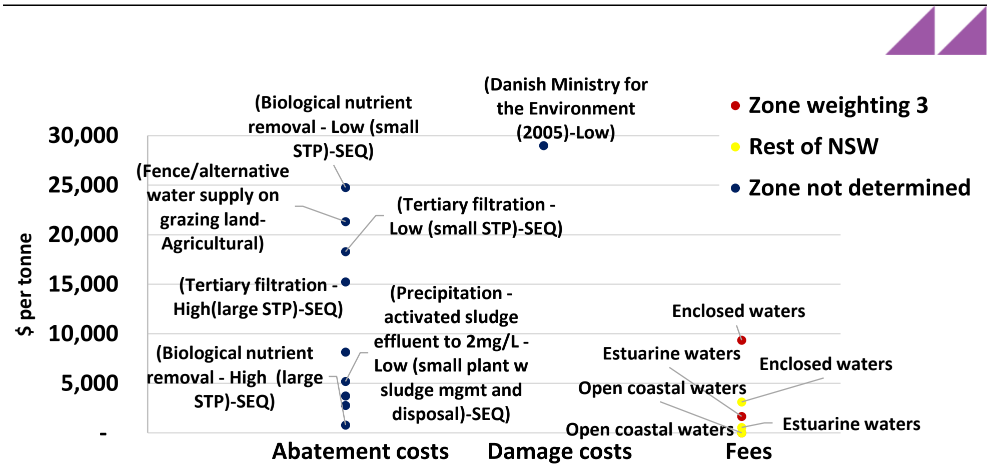


Figure 11 **MAC, MEC and LBL fees for phosphorus (< 30,000 $/t)**



Note: Labels not included for all points on chart to improve visibility

Table 10 **MAC, MEC and LBL fees for phosphorus**

Zone	MAC, MEC or LBL fee	$ per tonne	Abatement Measure (MAC) Study (MEC) Receiving waterway (LBL fee)	Data on abatement (MAC) Context of estimate (MEC)
Zone not determined	MAC	977,159	(Benchmark P removal Tertiary clarification-West Camden STP)	not available
Zone not determined	MAC	721,295	(Benchmark P removal Tertiary clarification-St Marys STP)	not available
Zone not determined	MAC	721,295	(Benchmark P removal Tertiary clarification-Quakers Hill STP)	not available
Zone not determined	MAC	463,517	(Eucalypt sawlog plantation - Small area-SEQ)	0.003 tonnes per Ha per year (assuming 19 Ha) in SEQ
Zone not determined	MAC	450,809	(Market garden - runoff reuse-Agricultural)	not available
Zone not determined	MAC	402,073	(Compost study at market garden-Agricultural)	not available
Zone not determined	MAC	347,245	(Greenhouse & vegetable garden - runoff reuse-Agricultural)	not available
Zone not determined	MAC	341,153	(P Polishing Contact filtration-Rouse Hill STP)	not available
Zone not determined	MAC	341,153	(P Polishing Contact filtration-Castle Hill STP)	not available
Zone not determined	MAC	269,267	(P Polishing Contact filtration-Wimnmalee STP)	not available
Zone not determined	MAC	240,635	(Greenhouse - wetland and recycling-Agricultural)	not available
Zone not determined	MAC	134,024	(Market garden - settlement pond-Agricultural)	not available
Zone not determined	MAC	123,790	(Eucalypt sawlog plantation - Large area-SEQ)	0.003 tonnes per Ha per year (assuming 3,695 Ha) in SEQ
Zone not determined	MAC	76,526	(Fencing and Riparian Revegetation - Grazing-SEQ)	5.8 tonnes per/farm/20 years in SEQ
Zone not determined	MAC	51,131	(Fencing and Riparian Revegetation - Intensive ag.-SEQ)	8.6 tonnes per/farm/20 years in SEQ

Zone not determined	MAC	32,185	(WSUD - Swales - (high) - Assumed maximum cost effectiveness-Greater Brisbane)	Total 1.81 tonnes phosphorus over 20 years in SEQ
Zone not determined	MAC	24,779	(Biological nutrient removal - Low (small STP)-SEQ)	Total 22 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	21,322	(Fence/alternative water supply on grazing land-Agricultural)	not available
Zone not determined	MAC	18,295	(Tertiary filtration - Low (small STP)-SEQ)	Total 29 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	15,245	(Tertiary filtration - High(large STP)-SEQ)	Total 876 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	8,161	(Precipitation - BNR effluent to 0.25 - 0.5 mg/L - Low (Small plant w sludge mgmt and disposal)-SEQ)	Total 183 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	5,194	(Precipitation - activated sludge effluent to 2mg/L - Low (small plant w sludge mgmt and disposal)-SEQ)	Total 657 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	3,739	(Precipitation - BNR effluent to 0.25 - 0.5 mg/L - High (Large plant w sludge mgmt)-SEQ)	Total 913 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	2,775	(Precipitation - activated sludge effluent to 2mg/L - High (large plant w sludge mgmt)-SEQ)	Total 3,285 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MAC	783	(Biological nutrient removal - High (large STP)-SEQ)	Total 830 tonnes of phosphorus load reduction over 20 years in SEQ
Zone not determined	MEC	119,000	(Danish Ministry for the Environment (2005)-High)	International literature study, contexts unknown
Zone not determined	MEC	29,000	(Danish Ministry for the Environment (2005)-Low)	International literature study, contexts unknown
Zone weighting 3	LBL Fee	9,364	Enclosed waters	
Rest of NSW	LBL Fee	3,121	Enclosed waters	

Zone weighting 3	LBL Fee	1,652	Estuarine waters
Rest of NSW	LBL Fee	551	Estuarine waters
Zone weighting 3	LBL Fee	-	Open coastal waters
Rest of NSW	LBL Fee	-	Open coastal waters

MAC for some measures are of a comparable level to LBL fees. Therefore, there remains uncertainty relating to which abatement measures remain as opportunities in NSW. Other abatement measures have a MAC higher than LBL fees but lower than the estimate for MEC.

As is the case with nitrogen, there may be opportunities to assess whether potential increases in the LBL fee could lead to external benefits that outweigh abatement costs, however, the same qualifications applying to nitrogen should be noted:

- The estimates of MEC are derived from a single international study. The environmental conditions, ecology and profile of use of the receiving waterways is likely to be substantially different; and
- Many of the abatement measures will already have been implemented to a greater or lesser degree in NSW. The existing level of treatment therefore needs to be borne in mind when considering the costs and benefits of further action.

3.3 Use of results

The results of MAC, MEC and LBL highlight areas where changes to load based fees could be considered. In particular, the results show where potential opportunities to incentivise abatement (through appropriate fee settings) that provides net benefits to society exist. While the results show potential opportunities, they are based on estimates with significant uncertainty, in terms of precision and scope for adoption in NSW. To robustly assess the costs and benefits of fee changes, further work would need to be undertaken to more precisely estimate:

- The external costs of pollution to water applicable to receiving waterways in NSW;
- The external costs of VOCs based specifically on NSW conditions;
- Current estimates of abatement measure cost based on existing level of controls; and
- Assessment of the scope for adopting abatement measures in NSW.

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Appendix A Abatement measures assessed

Air pollution

US non-road diesel standards in Australia (excluding < 19kW)

Non-road diesel engines include off-road equipment such as cranes, excavators, dozers and heavy forklifts. Market segments using off-road diesel equipment include industry (industrial, commercial, construction and mining), agriculture, power generation, lawn and garden, light commercial, marine and forestry.

Boulter & Kulkarni (2013) estimate the cost and emissions reductions achievable from a phased transition to US standards for non-road diesel engines (excluding engines < 19kW), noting that emissions performance of non-road diesel engines sold in Australia lag behind the performance of those sold in the EU and the US, based on earlier Cost Benefit Analysis modelling for a Consultation Regulatory Impact Statement (CRIS).

The study estimated that the non-road diesel standards would have a:

- Marginal cost of $8,915 / tonne of PM_{10} in NSW;
- Marginal abatement of 3,511 tonne PM_{10} per year
- Marginal cost of $9,191 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 3,406 tonne $PM_{2.5}$ per year.

Costs per tonne of NO_X ($1,209 per tonne) were inferred using the proportion of NO_X emissions reductions per tonne of $PM_{2.5}$ (estimated to be approximately 8 tonnes of NO_X per tonne of $PM_{2.5}$) based on figures D1 and D2 from Appendix D (Analysis of potential new abatement measures) of the study's report.

Measures relating to diesel trains

There are no regulations, or substantive programs addressing, emissions from locomotives in Australia. Boulter & Kulkarni (2013) estimate the cost and emissions reductions achievable from three measures which would reduce emissions from locomotives. These were:

- Driver assistance software (which also led to estimated fuel efficiency benefits);
- Requiring new locomotives to meet US 'Tier 4' emissions standards; and
- Replacing old line locomotive and requiring new locomotives to meet 'US Tier 4' emissions standards.

It should be noted that the two measures relating to emissions standards are mutually exclusive.

Diesel trains driver assistance software for line haul locomotives

The study estimated that driver assistance software would have a:

- Marginal cost of $5,263 / tonne of PM_{10} in NSW;
- Marginal abatement of 26 tonne PM_{10} per year;
- Marginal cost of $5,426 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 25 tonne $PM_{2.5}$ per year.

Costs per tonne of NO_X ($127 per tonne) were inferred using the proportion of NO_X emissions reductions per tonne of $PM_{2.5}$ (estimated to be approximately 43 tonnes of NO_X

per tonne of $PM_{2.5}$) based on Figures D19 and D20 from Appendix D (Analysis of potential new abatement measures) of the study's report.

Requiring new locomotives to meet US Tier 4 standards

The study estimated that requiring locomotives to meet US Tier 4 standards would have a:

- Marginal cost of $20,950 / tonne of PM_{10} in NSW;
- Marginal abatement of 69 tonne PM_{10} per year;
- Marginal cost of $21,598 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 67 tonne $PM_{2.5}$ per year.

Costs per tonne of NO_X ($787 per tonne) were inferred using the proportion of NO_X emissions reductions per tonne of $PM_{2.5}$ (estimated to be approximately 27 tonnes of NO_X per tonne of $PM_{2.5}$) based on figures D19 and D20 Appendix D (Analysis of potential new abatement measures) of the study's report.

Replacing old line locomotive and requiring new locomotives to meet US Tier 4

The study estimated that requiring old line locomotives to meet US Tier 4 standards would have a:

- Marginal cost of $102,666 / tonne of PM_{10} in NSW;
- Marginal abatement of 143 tonne PM_{10} per year;
- Marginal cost of $105,841 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 139 tonne $PM_{2.5}$ per year.

Costs per tonne of NO_X ($2,585 per tonne) were inferred using the proportion of NO_X emissions reductions per tonne of $PM_{2.5}$ (estimated to be approximately 41 tonnes of NO_X per tonne of $PM_{2.5}$) based on figures D19 and D20 from Appendix D (Analysis of potential new abatement measures) of the study's report.

Measures relating to shipping

The costs and benefits from two measures to address emissions from shipping around NSW ports have been estimated by Boulter & Kulkarni (2013). These measures are based on actions taken at international ports including actions being undertaken by the Port of Los Angeles and Long Beach in California as part of their 'Clean Air Action Plan'. The measures included:

- Mandatory use of low sulfur (0.1%) fuel while at berth; and
- A Memorandum of Understanding (MoU) with port operators and ship owners to reduce vessel speed for certain ocean transits to and from harbours.

Mandatory low sulfur fuel use by ships while at berth

The study estimated that mandating use of low sulfur fuel by ships while at berth would have a:

- Marginal cost of $46,049 / tonne of PM_{10} in NSW;
- Marginal abatement of 159 tonne PM_{10} per year in NSW;
- Marginal cost of $50,066 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 146 tonne $PM_{2.5}$ per year.

Costs per tonne of NO_X ($123,913 per tonne) were inferred using the proportion of NO_X emissions reductions per tonne of $PM_{2.5}$ (estimated to be approximately 0.4 tonnes of NO_X

per tonne of $PM_{2.5}$) based on figures D26 and D28 from Appendix D (Analysis of potential new abatement measures) of the study's report.

MOU to reduce shipping vessel speed for ocean transits

The study estimated that MOU to reduce shipping vessel speed for ocean transits would have a:

- Marginal cost of $9,779 / tonne of PM_{10} in NSW;
- Marginal abatement of 104 tonne PM_{10} per year;
- Marginal cost of $10,632 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 96 tonne $PM_{2.5}$ per year.

Costs per tonne of NO_X ($927 per tonne) were inferred using the proportion of NO_X emissions reductions per tonne of $PM_{2.5}$ (estimated to be approximately 11 tonnes of NO_X per tonne of $PM_{2.5}$) based on figures D26 and D28 from Appendix D (Analysis of potential new abatement measures) of the study's report.

Retrofitting high-polluting diesel engines & equipment with DPFs

Adoption of diesel standards will improve emissions performance of new diesel engines sold in Australia. However, measures can also be taken to address emissions performance of existing 'in-service' diesel engines. This includes expansion of measures such as the NSW EPA's 'Clean Machine' program, which involves the retrofitting of Diesel Particulate Filter to in-service diesel equipment in urban areas and at mine sites (Boulter & Kulkarni, 2013).

Retrofitting high-polluting (urban) diesel engines & equipment with DPFs

Based on data from the Clean Machine program, retrofitting high-polluting diesel equipment in urban areas has an estimated:

- Marginal cost of $21,781 / tonne of PM_{10} in NSW;
- Marginal abatement of 7 tonne PM_{10} per year in NSW;
- Marginal cost of $22,455 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 7 tonne $PM_{2.5}$ per year.

Diesel retrofit at mine sites (Emissions Reduction Program)

The potential for retrofitting diesel equipment at mine sites was estimated to have:

- Marginal cost of $15,416 / tonne of PM_{10} in NSW;
- Marginal abatement of 883 tonne PM_{10} per year in NSW;
- Marginal cost of $15,893 / tonne of $PM_{2.5}$ in NSW; and
- Marginal abatement of 857 tonne $PM_{2.5}$ per year.

Adoption of international best practice PM control measures at coal mines

Katestone Environment (2011) evaluated the scope to adopt international best practice measures for controlling coal dust on coal mines in the Hunter Valley, through research of current emissions and practices. The study found that an estimated 49% reduction in overall emissions of PM_{10} emissions could be achieved through an estimated $164 million expenditure on best practice measures. These estimates were, in turn used in the CBA by Boulter & Kulkarni (2013).

The adoption of international best practice PM control measures at coal mines were estimated to have:

- Marginal cost of $1,397 / tonne of PM_{10} in NSW;
- Marginal abatement of 39,874 tonne PM_{10} per year in NSW;
- Marginal cost of $9,115 / tonne of $PM_{2.5}$ in NSW;
- Marginal abatement of 6,110 tonne $PM_{2.5}$ per year

While Katestone Environment did not estimate the costs and abatement potential of total suspended particles (TSP), which are used as a proxy for coarse particles in this report, figures from the report have been used to estimate:

- Marginal cost of $4,068 / tonne (in 2014$) of TSP (coarse) PM in NSW;
- Marginal abatement of 88,606 tonne of TSP (coarse) PM per year

Coal fired power station NO_X control- low NO_X Burners

Low NO_X control mechanisms reduce the fuel to air ratio of coal burners to minimise the formation of thermal NO_X in the combustion process. Leaner fuel to air ratios allow NO_X reductions to below 500mg/Nm^3.

SKM (2010) estimates that this technology could be applied to all coal-fired generators in NSW for a total reduction in NO_X emissions of 60,736 t/year. According to SKM the operating cost of the technology would be negligible while capital cost would be around $215.36 million ($1.78/kW). SKM estimates that a program set up cost of $0.3 million would have to introduce the technology.

Petrol refinery vapour recovery and leak detection and repair

This measure to abate VOC emissions consist of the installation of vapour recovery units and leak detection and repair (LDAR) programs at refineries. While NSW refineries have ceased refinery operation the sites and infrastructure of these refineries is still used for fuel import operations.

SKM (2010) estimates that the cost of running an LDAR program for a refinery would be in the order of $500/t per year. According to SKM, installing the technology at refineries in Sydney would reduce VOC emissions by 289 t/year. SKM estimates that the measure would entail operating cost of $0.174 million per year and an initial program set up cost of $1 million.

Open coal mines - buffer zone initiative

The measure is designed to reduce the health impact of PM10 emissions from open cut coal mines by increasing the buffer zone between mining operations and land used by the public.

SKM (2010) estimates the abatement cost of this measure on the basis of land values in the upper Hunter of around $1,600/ha. According to SKM mining companies typically pay a multiple of the land value to acquire land for mining operations. Based on a multiple of three SKM estimates capital cost of reducing PM10 using this measure as $57.44 million. According to SKM the total abatement of PM10 emissions achievable with this measure would be 16,020 t/year.

Coal fired power station SCR

SCR technology reduces flue gas emissions at coal fired power stations by selectively reducing NO_X to nitrogen. SCR involves the injection of Urea into the flue gas stream prior to the flue gas entering a catalytic reduction unit. In the catalytic reduction unit flue gas passes through a catalyst plated honeycomb structure where the reduction reaction takes place.

The technology is able to reduce NO_X emissions from coal fired power stations by around 85%.

According to SKM (2010), capital cost for implementing SCR at coal fired power stations are estimated to be U$80/kW. Costs for replacing catalyst and other operating and maintenance cost are estimated to be in the order of U$ 2.4 million/year per boiler. SKM estimates that this technology can be applied to all coal fired generators in NSW for a total capital cost of U$964.8 million with operating cost in the order of U$43.2 million per year. SKM estimates the initial cost of setting up a program to introduce SCR to coal fired power as $0.3 million.

According to SKM the measure would allow for a reduction in NO_X emissions of 129,063 t/year.

Cement industry NO_X controls

This abatement measure involves the installation of Low NO_X burner controls at cement kilns and calciners. The basis of the technology is the staged combustion of fuel to achieve optimal thermal efficiency while reducing the formation of thermal NO_X formation.

SKM (2010) estimates that implementing NO_X controls in the cement industry in NSW would incur capital cost of U$2.58 million, annual operating cost of US$0.514 and an initial program set up fee of $0.15 million. According to SKM the technology would enable NO_X emissions reductions of 1,522 t/year.

CARB, 2008 Metal Plating and Coating Works

This method is designed to limit the emissions of VOC from metal painting and coating works by applying the same emission factor limits to meet the California Air Resource Board (CARB) 2008 requirements.

According to SKM (2010) estimates the VOC emission factors of CARB 2008 requirements are between 33% and 68% lower than those developed for the DECC 2003 Air Emissions Inventory. Applying this reduction in VOC emissions to product volume information obtained from the Australian Paint Manufacturers Federation SKM estimates that the measure could result in VOC emission reductions of 1,068 t/year. SKM estimates the capital cost of the measure as $2.64 million with additional implementation cost for the program of $0.1 million.

Printing VOC emissions control

This method involves the installation of an after-burner to printing presses so that VOCs are burned instead of being emitted into the atmosphere.

SKM (2010) estimates that this after-burner technology can reduce VOC emissions from printing presses by 70% or 2,172 t/year in the GMR. According to SKM the capital cost for implementing the measure would be $14.23 million with an additional $0.2 million for program set up.

NOx Controls on gas fired engines reciprocating engines

In June 2009, Sinclair Knight Merz (SKM) prepared a report on Financial Analysis of nitrogen oxide (NO_x) Controls on gas fired reciprocating engines for the NSW Department of the Environment (SKM, 2009). Technologies analysed by SKM include selective catalytic reduction (SCR) and lean burn technology.

Thermal NO_x emissions from reciprocating combustion engines are principally a function of combustion temperature, oxygen concentration and residence time of flue gases within the combustion chamber.

For engines operating in lean burn mode the concentration of oxygen is controlled so that excess air is available within the combustion chamber. This has the effect of reducing NO_x emissions. According to SKM implementing lean burn technology results in approximately 2% higher fuel consumption and is able to achieve a reduction in NO_x emissions to 250mg/m^3. SKM notes that lean burn technology is offered as standard by most manufacturers of reciprocating engine manufacturers and that capital cost are hence negligible. Operating costs for this abatement mechanism are incurred due to an increase in the generators heat rate.

SCR systems are installed downstream from the combustion chamber and reduce NO_x emissions by selectively reducing NO_x to nitrogen. SCR systems require the injection of liquid ammonia into the flue gas systems and a catalyst module. According to SKM, SCR systems remove 90% of NO_x to levels below 50mg/m^3. The capital cost of SCR systems depends on the size of the generator where larger generators offer economies of scale. Operating cost for SCR systems comprise urea for injection into the flue stream and periodic replacement of catalyst.

The information provided in the SKM report on its own is not sufficient to accurately estimate the cost of abatement on per tonne basis. To accurately assess the operating cost on a per tonne basis a number of assumptions had to be made. SKM states NO_x emissions on a concentration basis and does not provide the volume of flue gas emitted in each configuration. Furthermore the emissions concentration that are stated to be achieved seem to be thresholds that are met i.e. below 450mg/m^3, below 250mg/m^3 below 50mg/m^3 rather than actual emissions concentrations. As the installation of SCR systems is associated with fixed cost the cost of abatement will depend on the utilisation of the plant.

To make estimates of the per tonne cost of NO_x emissions we assume that current gas fired engine emissions are 4.6 kg/MWh (SKM, 2010). According to SKM SCR systems are able to reduce NO_x emissions by 90%, i.e. to 0.46kg/MWh. Based on a reduction in concentration from 450mg/m^3 to 250mg/m^3 we assume lean burn technology reduces emissions to a level 2.5kg/MWh. Further assumptions are listed in Table 11 below.

Table 11 **Assumptions**

Variable	Unit	Value	Source
Operating cost of SCR	$/MWh	4.53	SKM (2009)
Capacity factor	% of time plant is running at full output	80%	
Fuel cost	$/GJ	10	ACIL Allen assumption
Discount rate	-	7%	ACIL Allen assumption
Economic life	Years	20	ACIL Allen assumption

Note: $ are real 2014

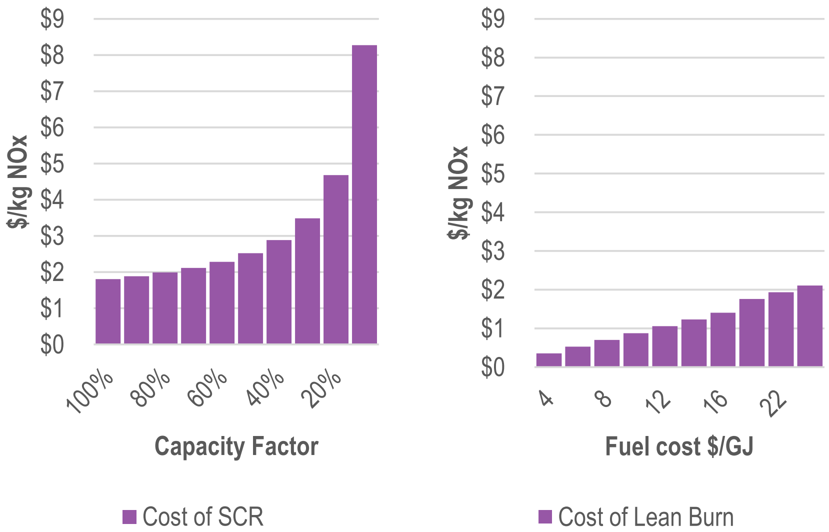
On the basis of the assumptions laid out in the table above, and heat rates provided in the SKM report we calculate the cost of the NO_x abatement as shown in Figure 12.

Figure 12 **Estimated cost of NOx abatement - $/kg**

Note: Please note the assumptions used to derive these figures
Source: ACIL Allen analysis

As noted above the cost of abatement is sensitive to a number of assumptions. Figure 13 below shows sensitivities of the cost of implementing lean burn technology and SCR on a 10MW plant assuming various capacity factors and gas fuel costs. The left panel shows the cost of abatement using SCR as a function of the plant's capacity factor. The right panel shows the cost of abatement using lean burn as a function of fuel cost.

Figure 13 **Sensitivities to estimated cost of NOx abatement - $/kg**



Source: ACIL Allen analysis

Based on the above an average of $910/tonne of NO_X abatement for lean burn and $2,580/tonne of NO_X abatement for SCR was adopted for the study.

SKM (2010) also produced an abatement cost estimate for applying SCR to NSW. However, the above updated analysis by ACIL Allen was used as it adopted more current assumptions.

SKM estimates that application of SCR on gas reciprocating engines would allow for the abatement of NO_X emissions of 2,630 t/year.

Expansion of Vapour Recovery at Petrol Service Stations

Petrol stations are a source of Volatile Organic Compound (VOC) emissions. Vapour Recovery (VR) technology can reduce emissions from various sources of emissions at petrol stations.

Stage 1 Vapour Recovery (VR1) technology captures vapours from underground storage tanks. Vapour is extracted from the storage tank while the tank is being filled by the road tanker. On returning to the terminal, the vapour is condensed into a liquid. Regulations have required VR1 to be in place at petrol stations in the majority of the Sydney metropolitan area since 1986 (DECCW, 2009).

Stage 2 Vapour Recovery (VR2) captures vapours that would otherwise be emitted while filling petrol into vehicles. It does this by recovering vapour that could escape through the space around the nozzle, using a vacuum pump, and returning this to the underground tank.

DECCW evaluated two options for expansion of VR across petrol stations in NSW. Its preferred vapour recovery expansion option was a phase-in of VR2 from mid 2010 to 2017 for all Sydney petrol stations with a throughput of greater than 3.5 million litres per year and Newcastle, Wollongong and Central Coast petrol service stations with a petrol throughput greater than 12 million litres per year (DECCW, 2009). This option also required VR1 compliance by 2014. The following data from the study was used to estimate MAC:

- A total cost (inclusive of capital, operating, disruption and compliance costs) of $106 million expressed in present value term;
- A total VOC reduction of 206,740 tonnes between 2010 and 2040.

Following the DECCW analysis, updates have been to VR1 and VR2 requirements at NSW service stations. The current requirements are described on the NSW EPA website (http://www.epa.nsw.gov.au/air/petrolvapour.htm).

Water pollution

Biological nutrient removal

Biological nutrient removal (BNR) is the removal of nitrogen and phosphorous from wastewater streams using biological organisms. BNR requires modification to the biological processes that are traditionally in place in waste water treatment plants. There are a range of processes that can be used to retro-fit waste water treatment plants with BNR.

Hall (2012) estimates that installing BNR technology on waste water treatment plants in South East Queensland would allow a reduction of nitrogen concentration of 12-27mg/l and a reduction in phosphorous concentration of 3-8mg/l.

Based on data from the US Environmental protection agency, Hall calculates capital cost for the installation of BNR technologies for three plant sizes. Capital cost for waste water plants with capacity of 0.379 ML/d are quoted as $0.87 million, for plants with a capacity of 3.79 ML/d capital cost are quoted as $2.18 million and for plants with a capacity of 37.9 ML/d capital cost are quoted as $7.36 million. Hall provides estimates of operating cost over a 20 year time horizon assuming a 3% discount factor as $0.52 million for a 0.379 ML/d plant, $1.3 million for a 3.79ML/d plant and $4.38 for a 37.9 ML/d plant.

Reuse of effluent for controlled irrigation

Effluent from waste water treatment plants can be used for the controlled irrigation of plantations. Using effluent for irrigation provides fertiliser to the plantation and is a means of additional waste water treatment.

Hall (2012) estimates the cost of controlled effluent irrigation systems for a number of different plantation types. The cost of abatement from these measures takes into account the plantation's product value.

In humid climates the most cost effective option of controlled effluent irrigation is reported to be flood irrigation of eucalypt sawlog plantations (Hall, 2012). Controlled effluent irrigation of pine pulpwood plantations using a sprinkler system is quoted as being the least cost-effective option for effluent irrigation in humid climates. In hay sorghum plantations lucerne hay and sorghum[6] are grown in a rotation cycle pattern where lucerne hay is grown for 4 years followed by 1 year of sorghum. While hay takes up nutrients which can be removed on a regular basis the sorghum provides a disease control break and removes build ups of nitrogen in the soil.

Hall based his estimates of the nutrient removal capacity of controlled effluent irrigation of eucalypt and pinewood plantations on the long term uptake capability of eucalyptus grandis i.e. 80 kg/ha/year for nitrogen and 3 kg/ha.year. Hall assumed a nitrogen uptake rate of 517kg/ha and a phosphorous uptake rate of 97 kg/ha for Phosphorous for hay and sorghum plantations. **Table A12** provides an overview of the key parameters of each of the effluent irrigation measures included in this study.

Table A12 Controlled effluent irrigation cost parameters

Nutrient removal from:	Effluent Volume	Area required	Cost per ha per year
	ML/d	(ha)	$2010/ha/year
Hay and sorghum rotation small area	0.5	14	5087
Hay and sorghum rotation large area	100	279	1403
Pine and pulpwood plantation small area	0.5	20	5065
Pine and pulpwood plantation large area	10	4012	2546
Eucalypt sawlog plantation small area	0.5	19	3748
Eucalypt sawlog plantation large area	100	3695	1001

Source: Hall (2012)

Precipitation – active sludge effluent

Precipitation is used to reduce emissions of phosphorous from sewerage treatment plants. Phosphorous removal through precipitation involves adding chemical agents to the wastewater stream. The chemicals react with phosphorous to form compounds that can be

6 Note that Lucerne hay and sorghum are generally grown as fodder crop and whether reuse of effluent for irrigation is allowed under existing regulations should be considered.

removed from the effluent through sedimentation. The nitrogen and phosphorous rich sediment can then be disposed of separately.

The cost on a per tonne basis of applying this method of abatement depend on the concentration of pollutants in the waste water stream. Precipitation was considered for application to effluent from conventional activated sludge sewerage plants and to effluent from a sewerage plant that had already undergone biological nutrient removal (BNR). In the case of the effluent from the conventional sewerage treatment plant phosphorous concentrations are assumed to be lowered by 75% to 2mg/L. In case of the effluent from sewerage treatment plant using BNR phosphorous concentrations were reduced from 1-2 mg/L to 0.25-0.5mg/L.

Capital cost of precipitation for treating BNR and activated sludge effluent are the same but depend on the sewerage treatment plant size. Hall (2012) quotes capital cost of $0.26 million for a 20 ML/d plant and $0.52 million for 100ML/d plant. Operating cost are incurred for the purchase of precipitation agents, maintenance and sludge management and disposal cost. Sludge management and disposal cost are lower for precipitation of effluent from a plant using BNR. Hall quotes present values of operating cost and sludge management and disposal as laid out in **Table A13**.

Table A13 Precipitation cost parameters

Nutrient removal from:	Plant capacity	Precipitation capital cost	Present value of operating cost	Present value of sludge management and disposal
	ML/d	$2010 million	$2010 million	$2010 million
BNR effluent	20	0.26	0.21	0.55
BNR effluent	100	0.52	0.75	2.74
Activated sludge effluent	20	0.26	0.21	2.05
Activated sludge effluent	100	0.52	0.75	10.24

Note: Present value calculation assumes a 3% discount rate

Source: Hall (2012)

Tertiary filtration

Tertiary filtration systems remove fine, non-settling material in the effluent of sewerage treatment plants. Tertiary filtration reduces the emissions of nitrogen and phosphorous. Table A14 provides an overview of the key cost parameters of tertiary filtration in sewerage treatment plants.

Table A14 Tertiary filtration cost parameters

Sewerage treatment plant (STP) size	Plant capacity	Change in nitrogen concentration -high	Change in nitrogen concentration -low	Change in phosphorous concentration -high	Change in phosphorous concentration -low	Total capital and operating cost over 20 years
	ML/d	mg/L	mg/L	mg/L	mg/L	$2010 million
Small	5	3	1	1.8	0.8	6.4
Large	100	3	1	1.2	0.3	36

Source: Hall (2012)

Fencing and riparian revegetation

Riparian revegetation is a measure to reduce suspended solids, nitrogen and phosphorous from farming activities. This is achieved through the establishment of off-stream watering facilities for livestock and introduction of revegetated buffer strips between farming activities and rivers.

Hall (2012) cites pollution removal efficiencies of 90% for suspended solids, 70% for nitrogen and 80% for phosphorous.

The amount of pollution that can be abated by the measure also depend on the farming activity as the pollution emissions differ between farming methods. **Table A15** provides an overview for some of the key parameters of riparian revegetation.

Table A15 Riparian revegetation cost parameters

Farming activity:	Farm area	Revegetation area	Suspended solids load reduction	Nitrogen load reduction	Phosphorous load reduction	Total cost in present value terms
	Ha	ha	t/farm/20years	t/farm/20years	t/farm/20 years	$2010
Grazing	1,000	50	5,616	35	5.8	928,297
Intensive Agriculture	1,000	50	11,880	87	8.6	928,297

Note: Present value calculation implies a 3% discount rate

Source: Hall (2012)

Water sensitive urban design (WSUD)

WSUD incorporates features into urban design that help to reduce water pollution from storm water discharge. WSUD can reduce concentrations of suspended solids, nitrogen and phosphorous.

Bioretention

Bioretention systems are vegetated stormwater treatment technologies that incorporate planting of grass and trees as well as soil modifications. Hall (2012) quotes capital cost for a bioretention system in a residential with sloping geography Brisbane as $1.6 million with renewal cost of $0.64 million after ten years and decommissioning cost of $0.64 million after 20 years. Operating cost were quoted to be $19,695/year. According to Hall the bioretention system enabled a reduction of suspended solids by 67,860 kg/year, phosphorous by 103.9 kg/year and nitrogen by 313.14 kg/year.

Swales

Another technique used in WSUD are swales. Swales are troughs designed to slow the flow of water runoff and facilitate the infiltration of moisture into the soil while retaining suspended solids and reducing phosphorous and nitrogen concentration.

Cost and effectiveness of swales are highly dependent on local conditions. Construction cost can vary based on the amount of earthworks required while operating cost will depend on the amount of weed removal replanting required. Hall (2012) provides confidence intervals for capital and operating cost for swale implementation shown in **Table A16**.

Table A16 Swales cost parameters

Farming activity:	Capital cost	Operating cost
	\$2010/m^2/year	\$2010/m^2/year
Upper 95% confidence limit	28	6
Lower 95% confidence limit	13	1.9

Note: Present value calculation assumes a 3% discount rate
Source: Hall (2012)

The overall cost of pollution abatement using swales is dependent on the proportion of a catchment area to which swales are applied. One approach is to apply the swales to achieve a maximum pollutant load reduction. Another approach is to apply the swales to achieve the most cost effective pollutant reduction. Each approach can be expressed as the percentage of the catchment area that is taken up by swale top area. This percentage differs from region to region, reduction approach (i.e. maximum reduction or most cost effective reduction) and the characteristics of the catchment area (i.e. high nitrogen concentrations versus high suspended solids concentration) (Hall, 2012).

Rainwater tanks

While the installation of rainwater tanks serves the primary goal of providing an alternative water supply to households their installation is also a diffuse water pollution abatement strategy. Rainwater tanks can reduce pollution of suspended solids, nitrogen and phosphorous. For the installation of 951 5kL rainwater tank Hall (2012) quotes capital cost and possible pollution reductions as shown in **Table A17**.

Table A17 Rainwater tank cost parameters

Tank yield	Assumed number of 5 kL rainwater tanks	Capital cost	Operating cost	Reduction in suspended solids	Reduction in nitrogen	Reduction in phosphorous
kL/year	no.	2010 \$m	2010 \$m per year	t/20years	t/20years	t/20years
30	951	2.85	0.09	17.49	0.09	1.02
70	951	2.85	0.09	40.8	0.2	2.38

Note: Assumes the installation of 951 5kL rain water tanks
Source: Hall (2012)

Storm water harvesting

Storm water harvesting involve the collection, treatment, storage and use of stormwater runoff from urban areas and provides a source of diffuse water pollution abatement. The cost effectiveness of implementing storm water harvesting depends on the size of the installation and the concentration of pollutants captured in the stormwater. Hall (2012) quotes capital and operating cost as shown in **Table A18**. High and low estimates for nitrogen and phosphorous pollution reduction are also included in **Table A18**.

Table A18 Stormwater harvesting cost parameters

Stormwater reuse volume	Capital cost	Present value of operating cost	Reduction in nitrogen - low	Reduction in nitrogen - high	Reduction in phosphorous -low	Reduction in phosphorous -high
ML/year	$2010 million	$2010 million	t/20years	t/20years	t/20years	t/20years
5	0.45	0.53	0.01575	0.135	0.004	0.0125
50	1.05	1.23	0.1575	1.35	0.04	0.125

Note: Present value calculation assumes a 3% discount rate
Source: Hall (2012)

Constructed wetlands

Constructed wetlands remove pollutants from stormwater by creating a wetland that filters and removes pollution from stormwater. A combination of physical, chemical and biological processes remove water pollutants. BDA Group (2006) provided the cost effectiveness of using constructed wetlands to remove nitrogen in three Australian catchments:

- South Creek NSW at $10/kg/year;
- Port Phillip Bay, VIC at $80/kg/year; and
- Port Waterways, SA at $40-$80/kg/year.

Better treatment at Sewerage Treatment Plants (STPs)

BDA Group (2006) estimated the costs of upgrading STP to treat discharges to a higher degree than was the case at that time. They were noted as representative costs, rather than any type of average, as they only included the cost of upgrades to municipal STPs and excluded some plant. The cost effectiveness of using better treatment at STPs was provided as:

- South Creek NSW at $10,000/kg nitrogen/year;
- Port Phillip Bay, VIC at $50/kg nitrogen/year; and
- Port Waterways, SA at $200/kg nitrogen/year.

Other point sources at Port Waterways, SA

BDA Group (2006) also estimated the costs of reducing nitrogen pollution at Port Waterways, SA through measures from ‘other [industrial] point sources’. These were estimated as $12/kg nitrogen/year. The estimate appears to have been derived from an early study based on cleaner production activities at a Penrice soda plant which had spent an approximate $12,500 per tonne of total nitrogen (BDA Group, 2004).

Abatement from agricultural sources

BDA Group (2006) provides a range of estimates of the cost effectiveness of nitrogen abatement from agricultural sources for the catchments of South Creek NSW, Port Phillip Bay VIC and Port Waterways SA. These included:

- ‘engineering’ (structural) solutions such as buffer strips, revegetation and/or fencing of riparian zones; and
- Diffuse sources including the adoption of ‘best management practices’ (e.g. through the preparation and implementation of Property Management Plans) and modifying fertilizer use by horticulture.

The cost effectiveness estimates are provided below.

Table A19 Cost effectiveness of abatement actions from agricultural sources in Australian catchments

Abatement measure to reduce nitrogen	Capital cost	Present value of operating cost	Reduction in nitrogen - low
	$/kg/yr	$/kg/yr	$/kg/yr
Modifying fertilizer use by horticulture	< $5	< $5	-
Riparian restoration	$10	-	< $5
Buffer strips on horticultural land	< $15	-	-
Best practice for cropping	-	$55	-
Best practice for grazing	-	$75	-

Source: Table 9, BDA Group (2006)

Reducing pollution from selected Sewerage Treatment Plants (STPs)

BDA Group (2006) used nitrogen and phosphorus removal cost curves ($ per kilogram of pollutant reduction based on level of effluent quality) to estimate the cost of pollution reduction from various STPs in the Hawkesbury-Nepean. For each plant a representative technology/process was assumed (with accompanying qualifiers that processes may not be suitable in all instances).

Technologies or processes included:

- Denitrification (process to remove nitrates through the use of microbes);
- Nitrogen removal through methanol dosing;
- ‘Contact’ filtration;
- Tertiary clarification; and
- Reverse osmosis.

Table A20 Estimated costs of pollutant removal from selected STPs

STP	Technology process	$/kg nitrogen reduced	$/kg phosphorus reduced
Castle Hill STP	Advanced denitrification MLE 40% anoxic	5	
West Camden STP	Pushed dentrification MLE 40% anoxic	6	
Wimnmalee STP	Enhanced denitrification add fermentation	12	
St Marys STP	Benchmark N removal Bardenpho II Methanol dosing	18	
Quakers Hill STP	Benchmark N removal Bardenpho II Methanol dosing	18	
Riverstone STP	Benchmark N removal Bardenpho II Methanol dosing	18	
Rouse Hill STP	Benchmark N removal Bardenpho II Methanol dosing	21	
West Hornsby STP	Benchmark N removal Bardenpho II Methanol dosing	21	
Hornsby heights STP	Benchmark N removal Bardenpho II Methanol dosing	25	
North Richmond STP	Benchmark N removal Bardenpho II Methanol dosing	33	
Richmond STP	Benchmark N removal Bardenpho II Methanol dosing	33	
Wimnmalee STP	P Polishing Contact filtration		221
Rouse Hill STP	P Polishing Contact filtration		280
Castle Hill STP	P Polishing Contact filtration		280
St Marys STP	Benchmark P removal Tertiary clarification		592
Quakers Hill STP	Benchmark P removal Tertiary clarification		592
West Camden STP	Benchmark P removal Tertiary clarification		802
North Richmond STP	Benchmark P removal Tertiary clarification		1,895
Richmond STP	Benchmark P removal Tertiary clarification		1,895
Riverstone STP	Reverse osmosis		173,766

Source: Table 8 and Table 9, BDA Group (2006)

The report noted that if process assumed were suitable for each of the plants they could potentially provide total reductions of around 2,300 kilograms of phosphorus and 210,000 kilograms of nitrogen per year.

Diffuse sources of abatement from South Creek pilot scheme

BDA Group (2006) presented data from the South Creek pilot nutrient offset scheme, as valuable data for reducing nutrients from agricultural sources in the Hawkesbury-Nepean. These included pollutant reduction measures at market gardens, greenhouses and grazing. Estimated cost-effectiveness from these sources are provided below:

Table A21 Estimated costs of pollutant removal from selected STPs

STP	Cost per kg of nitrogen	Cost per kg of phosphorus
Market garden - runoff reuse-Agricultural	100	740
Market garden - settlement pond-Agricultural	25	220
Greenhouse - wetland and recycling-Agricultural	100	395
Greenhouse & vegetable garden - runoff reuse-Agricultural	80	570
Compost study at market garden-Agricultural	105	660
Fence/alternative water supply on grazing land-Agricultural	440	35

Source: Table 11, BDA Group (2006)

Appendix B Externality cost estimates in literature

The following studies were reviewed for estimates of Marginal Externality Cost (MEC).

Boulter & Kulkarni (2013)

The study was undertaken by consultants Pacific Environment Limited (PEL) and Marsden Jacob Associates (MJA) and provided economic data to support a review of the framework for managing airborne particulate matter (PM) in Australia. It involved a Cost Benefit Analysis (CBA) of various hypothetical air quality standards, weighing the costs of abatement measures against the benefits of:

- Reductions in PM emissions or reductions in exposure to PM; and
- Co-benefits (reduced fuel consumption, reduced NO_x emissions and reduced greenhouse-gas (GHG) emissions).

Marginal Abatement Cost Curves (MACC), damage costs for PM and damage costs for NO_X were developed for each Australian jurisdiction PM damage costs were built on earlier work by PAE Holmes (2013), which estimated damage costs for Australian regions by population density. The damage cost functions were based on UK damage cost estimates by DEFRA (2012). DEFRA used an impact-pathway approach and the resultant UK damage cost estimates were adjusted for Australian estimated value of life and population densities.

A further adjustment was made to NO_X damage functions to account for differences in its contribution to the formation of secondary particles in Australia and differences in population exposure.

$PM_{2.5}$ MEC estimates for NSW were taken from Table 5.1 and are shown below:

Table B1 **Estimates of $PM_{2.5}$ damage costs for NSW (AUD 2011$)**

SUA code	SUA name	Area (km2)	2011 Population	2011 Pop. density (people/km^2)	2011 unit damage costs (A$/tonne PM2.5)
1000	Not in any Significant Urban Area	788,116	999,873	1	$360
1006	Bowral – Mittagong	422	34,861	83	$23,000
1009	Central Coast	566	304,755	538	$150,000
1010	Cessnock	69	20,262	294	$82,000
1017	Kurri Kurri - Weston	91	16,198	179	$50,000
1019	Lithgow	120	12,251	102	$29,000
1020	Morisset – Cooranbong	341	21,775	64	$18,000
1021	Muswellbrook	262	11,791	45	$13,000
1022	Nelson Bay – Corlette	116	25,072	217	$61,000
1023	Newcastle - Maitland	1,019	398,770	391	$110,000
1028	Singleton	127	16,133	127	$36,000
1030	Sydney	4,064	4,028,525	991	$280,000
1035	Wollongong	572	268,944	470	$130,000

Source: Table 5.1, Boulter & Kulkarni (2013)

NO_X MEC estimates for NSW were taken from Table 5.5 and are shown below:

Table B2 **Estimates of NO_X damage costs for NSW (AUD 2011$)**

State	Area name	Total area (km2)	Total 2011 population	Total 2011 pop. density (people/km^2)	2011 unit damage cost (A$/tonne NO_X)
NSW	Greater Sydney	4,630	4,333,280	936	$4,992
NSW	Other NSW	795,710	2,505,659	3.1	$17

Source: Table 5.5, Boulter & Kulkarni (2013)

Based on the estimates and corresponding population densities, the implied coefficients (dollars of damage cost per unit of population density) for PM2.5 and NO_X are:

- Approximately $281 per people/km^2 for $PM_{2.5}$ emissions in NSW; and
- Approximately $5.40 per people/km^2 for $PM_{2.5}$ emissions in NSW.

BDA Group (2014)

The report provided a comparative analysis of schemes similar to the LBL, operating in Australia and overseas. It found that pollution fees were more common in Europe than other OECD countries. Four case studies were provided:

- Swedish NOx fee;
- French industrial air emission fees;
- Danish wastewater fees; and
- US National Pollution Discharge Elimination System (NPDES) fees to air and water.

The report provided observations and lessons from both the case studies and the broader review as well as noting emerging trends.

Table 2.7 of the study compares NSW LBL fees at the time of the study with estimates of the damage costs of PM10, nitrogen oxides and volatile organic compounds from literature:

Table B3 **Comparison of NSW LBL fees for key air pollutants with estimated damage costs from literature**

Pollutant	Marginal fee per tonne payable under LBL (2012-13) (approx.)	Estimated damage cost per tonne* **Watkiss (2002)** (updated to $A 2010)	Estimated damage cost per tonne* **DECCW (2009)** ($A 2010)
Particulate matter (PM10)	$533 - $1,066	$116,600 - $427,500	$55,825 - $235,260
Nitrogen oxides	$38 - $2,148	$300 - $2,200	$155 - $1,055
Volatile organic compounds	$28 - $1,575	$200 - $1,100	$4,200

Source: Table 2.7, BDA Group, (2014)

Estimates by Watkiss (2002) are from a Commonwealth Government study relating to the air pollutions costs of transport in Australia. The values reported by DECCW were drawn from Department of Infrastructure, Transport, Regional Development and Local Government (DITRDLG) RIS on vehicle emissions standards (DITRDLG, 2009).

The estimates from Watkiss (2002) were developed using Europe's ExternE project (which in turn used an impact pathway approach to estimate the damage cost of various pollutants). The European estimates were adjusted for Australian conditions controlling for population density. The higher end of the range was used to estimate damage costs for inner areas of large capital cities (Melbourne, Sydney, Brisbane, Adelaide and Perth) and the lower end of the range was used to estimate damage cost for ‘other urban areas’ (Canberra, Hobart and Darwin).

The RIS on vehicle emissions standards used a simple average from a number of earlier estimates of Australian damage costs (including the Watkiss study) and a +/- 50% range to reflect uncertainty. The higher end of the range was used to estimate damage cost for capital cities and the lower end of the range was used to estimate damage cost for rest of Australia.

Table 4.8 of the study provides a range of values for environmental effects of wastewater pollutants from an economic analysis of wastewater charges undertaken by the Danish Ministry of Environment (2005).

Table B4 **Range of values for environmental effects of wastewater pollutants**

Pollutant	DKK per kg	A$ per kg
Nitrogen	8 – 141	1.6 – 29
Phosphorus	141 – 580	29 – 119

Source: Table 4.8, BDA Group (2014)

The study is published in Danish but includes an English ‘Summary and conclusion’ chapter. The chapter notes that estimates were derived through ‘an international literature study in order to find applicable prices’, however very little further information about these studies was provided. One study referred to as a 'Swedish-Polish' study provides the upper bound estimate for nitrogen and lower bound estimate for phosphorus of DKK 141. The estimates were based on a stated preference willingness to pay (WTP) estimate for reductions in discharges to the Baltic Sea. The transferability of these estimates to NSW is limited given that the environmental conditions, ecology and profile of use of the receiving waterways is likely to be substantially different.

Australian Academy of Technological Sciences and Engineering (ATSE) (2009)

The Academy assessed the external social and environment costs associated with electricity generating technologies. At the time of the study, the Australian government had announced the Carbon Pollution Reduction Scheme (CPRS) policy. The study recommended that the externalities associated with electricity generation need to be better understood, communicated and incorporated into the policy process.

The study noted that greater focus on externalities could help maximise social and environmental benefit and that major gaps in valuing externalities existed at the time. The study adopted a full life-cycle approach to generate external costs by technology expressed per unit of energy.

The study derived estimates based on the European Union (EU) ExternE Project and scaled to account for differences in population density. In particular, a scaling factor was estimated based on the relative population densities within 1,000 km of the generators included in the ExternE and NSW studies.

Estimates for PM_{10} and NO_X (based on emissions from coal power stations) were taken from Table 23.

Table B5 **PM_{10} and NO_X damage cost based on coal power station emissions**

Pollutant	Australian damage cost $A/kg
PM_{10}	41 – 119
NO_X	6.9 – 18

Source: Table 23, ATSE (2009)

Colagiuri, et al. (2012)

The independent report was commissions by Beyond Zero Emissions to examine and summarise research evidence relating to the social harms of mining activity for communities living near coal mines and in particular, to relate the issues to the Hunter Region of NSW. The study noted clear indications within the international health research literature of serious health and social harms to surrounding communities associated with coal mining and coal fired power stations.

While the study examined studies relating to the Hunter Region, it noted that few Australian studies at the time directly examined the health effects of coal mining or coal burning power station on local communities. It therefore also drew on peer reviewed literature from the Appalachian coal mining region of the United States and other international studies.

The report noted a range of estimates from a US study Levy, et al. (2009) that examined the uncertainties and variability associated with estimating health related costs based on 407 coal-fired powers stations. Median of plant specific damage costs were noted as ranging from:

- $30,000 to $500,000(USD) per ton of $PM_{2.5}$; and
- $500 to $15,000(USD) per ton of NO_X.

The health-related damages from coal-fired power plant emissions were reported to vary by function of plant, site, and population characteristics. However, the extent to which the estimates would apply to power stations in NSW was not evaluated and should therefore be considered as more uncertain compared to studies specifically relating to Australian conditions.

BDA Group (2006)

BDA Group's report outlined the rationale, objectives and proposed revised fee structure for South Australian prescribed activity licence fees. The fee structure was devised following an evaluation of conceptual options. The criteria used to evaluate fee options were effectiveness and efficiency (in recovering costs), cost reflectiveness (to provide equity), transparency, predictability, availability of incentives to improve environmental performance and ability to cope with changes in licenced activities. BDA Group then developed a proposed fee structure, incorporating feedback from stakeholder consultations, which comprised:

- A flat minimum component (to cover administrative costs);
- An environmental management component (to reflect relative regulatory effort for each activity group); and
- A load based component (to provide a price signal to reduce pollutants that contribute to environmental problems in South Australia).

A system of pollutant weightings were devised based on a logarithmic scale. The weights were intended to reflect the potential harm of each pollutant.

Although BDA noted that the settings for load based fees were not attempting to internalise the external impacts of the key pollutants, they provided a comparison to the environmental impact values of different pollutants using NSW EPA's ENVALUE database including:

— A median value of $1,385 per tonne of NO_X based on sixteen studies from the US and Europe; and

— A median value of $1,440 per tonne of VOC based on nine studies.

The sources or context for these estimates was not provided.

Appendix C NSW EPA Pollutant Weightings

Table C1 **Air pollutant weightings from POEO Regulations**

Pollutant	Definition	Weighting
	Total arsenic calculated using the method prescribed in the Approved Methods Publication	52,000
Benzene	Benzene	740
Benzo[a]pyrene (equivalent)	Benzo[a]pyrene plus 0.1 times the mass of benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene and ideno[1,2,3-c,d]pyrene plus 0.4 times the mass of dibenz[a,h]anthracene	29,000
Coarse particulates	All solid particulates entrained in air but not including fine particulates as defined in this Table	18
Fine particulates	The fraction of all solid particulates entrained in air with an aerodynamic diameter smaller than 10 micrometres	125
Fluoride	Fluorine, hydrogen fluoride and all other inorganic fluoride compounds expressed as hydrogen fluoride equivalent	84
Hydrogen sulfide	Hydrogen sulphide	320
Lead	Total lead calculated using the method prescribed in the Approved Methods Publication	11,000
Mercury	Total mercury calculated using the method prescribed in the Approved Methods Publication	110,000
Nitrogen oxides and nitrogen oxides (summer)	The sum of nitrogen oxide and nitrogen dioxide expressed as nitrogen dioxide equivalent	9
Sulfur oxides	Sulfur dioxide and (where specified in the load calculation protocol for the activity or in the licence for the premises) sulfur trioxide and sulfuric acid mist	2.2
VOCs and VOCs (summer)	See clause 3 (1) for the definition of VOC	6.6

Source: POEO Regulations, Part 2 – Pollutant weightings, Table 1 Air pollutants

Table C2 **Water pollutant weightings from POEO Regulations**

Pollutant	Definition	Open coastal waters	Estuarine waters	Enclosed waters
Arsenic	Total arsenic calculated using the method prescribed in the Approved Methods Publication	2,500	2,500	2,500
BOD 5	Biochemical oxygen demand calculated using the method prescribed in the Approved Methods Publication	0	0.5	1
Cadmium	Total cadmium calculated using the method prescribed in the Approved Methods Publication	67,000	67,000	67,000
Chromium	All trivalent chromium plus ten times hexavalent chromium, whether present in elemental form or contained in compounds or complexes	840	4,200	4,200
Copper	Total copper calculated using the method prescribed in the Approved Methods Publication	1,700	1,700	1,700
Lead	Total lead calculated using the method prescribed in the Approved Methods Publication	6,400	6,400	6,400
Mercury	Total mercury calculated using the method prescribed in the Approved Methods Publication	180,000	180,000	180,000
Oil and grease	Oil and grease calculated using the method prescribed in the Approved Methods Publication	13	30	74
Pesticides and PCBs	The sum of aldrin, chlordane, DDE, DDT, dieldrin, endosulphan (a,b), heptachlor, lindane, PCBs, chlorpyrifos, diazinon, malathion and parathion	930,000	930,000	930,000
Salt - The pollutant weighting for salt is zero if the salt is discharged into naturally salty surface waters with an electrical conductivity of more than 10,000 micro siemens per centimetre	Total dissolved solids calculated using the conductivity method prescribed in the Approved Methods Publication, or using a method provided in a load calculation protocol for the activity	0	0	8.4
Selenium	Total selenium calculated using the method prescribed in the Approved Methods Publication	710	10,000	10,000
Total nitrogen	Total nitrogen calculated using the method prescribed in the Approved Methods Publication	6	12	23
Total PAHs	The total of polyaromatic hydrocarbons	3,800	3,800	3,800
Total phenolics	Total phenolic compounds calculated using the method prescribed in the Approved Methods Publication	4,900	4,900	4,900
Total phosphorus	Total phosphorus calculated using the method prescribed in the Approved Methods Publication	0	120	680
Total suspended solids	Non-filterable solids calculated using the method prescribed in the Approved Methods Publication	9.5	9.5	78
Zinc	Total zinc calculated using the method prescribed in the Approved Methods Publication	7	7	7

Source: POEO Regulations, Part 2 – Pollutant weightings, Table 2 Water pollutants

Appendix D NSW EPA Critical Zone Weightings

Table D1 **Air pollutant critical zone weightings from POEO Regulations**

Pollutant	Local government areas in zone	Weighting
Nitrogen oxides and VOCs	Local government areas in the Sydney basin area, Blue Mountains City, Kiama, Shellharbour City and Wollongong City	7
Nitrogen oxides and VOCs	Cessnock City, Gosford City, Lake Macquarie City, Maitland City, Muswellbrook, Newcastle City, Port Stephens, Singleton, Wollondilly, Wyong	2

Note: The catchments referred to above, are the catchments as shown on the maps marked "Catchments of NSW displayed for the purpose of Load-Based Licensing" deposited in the office of the EPA.

Source: POEO Regulations, Part 1 – Pollutant critical zone weightings, Table 1

Table D2 **Water pollutant critical zone weightings from POEO Regulations**

Pollutant	Catchments in zone	Weighting
Salt	Benanee, Bulloo River, Castlereagh, Condamine/Culgoa, Cooper Creek, Darling, Lachlan, Lake Bancannia, Lake Frome, Macquarie River, Moonie, Murray Riverina, Murray (Lower), Murray (Upper), Murrumbidgee, Paroo, Warrego	3
Total phosphorus and total nitrogen	Benanee, Border Rivers, Bulloo River, Castlereagh, Condamine/Culgoa, Cooper Creek, Darling, Gwydir, Hawkesbury-Nepean, Lachlan, Lake Bancannia, Lake Frome, Macquarie River, Moonie, Murray Riverina, Murray (Lower), Murray (Upper), Murrumbidgee, Namoi, Paroo, Warrego	3

Source: POEO Regulations, Part 1 – Pollutant critical zone weightings, Table 2

Appendix E Effect of adjustment for cost allocation

Pollutant	Measure	Based on original study estimate ($/t)	Estimate after cost allocation ($/t)	Adjustment
NO_X	US non-road diesel standards in Australia (excluding < 19kW)	2,457	1,229	50%
NO_X	Diesel trains driver assistance software for line haul locomotives	259	130	50%
NO_X	Requiring new locomotives to meet US Tier 4 standards	1,600	800	50%
NO_X	Replacing old line locomotive and requiring new locomotives to meet US Tier 4	5,256	2,628	50%
NO_X	Mandatory low sulfur fuel use by ships while at berth	251,918	125,959	50%
NO_X	MOU to reduce shipping vessel speed for ocean transits	1,884	942	50%
NO_X	Coal Fired Power Station NOx Control - Low NOx Burners	263	263	No adjustment
NO_X	Coal fired power station SCR	881	881	No adjustment
NO_X	Cement industry NOx control	653	653	No adjustment
NO_X	Adoption of SCR on gas reciprocating engines	2,580	2,580	No adjustment
NO_X	Adoption of lean burn on gas reciprocating engines	910	910	No adjustment
NO_X	Adoption of lean burn on gas reciprocating engines	910	910	No adjustment
VOCs	Refinery Vapour Recovery and Leak Detection and Repair	1,863	1,863	No adjustment
VOCs	Expansion of Vapour Recovery at Petrol Service Stations	1,501	1,501	No adjustment
VOCs	CARB, 2008 Metal plating and coataing works	-	-	No adjustment
VOCs	Printing VOC emission control	-	-	No adjustment
PM_{10}	US non-road diesel standards in Australia (excluding < 19kW)	18,124	9,062	50%
PM_{10}	Diesel trains driver assistance software for line haul locomotives	10,700	5,350	50%
PM_{10}	Requiring new locomotives to meet US Tier 4 standards	42,592	21,296	50%
PM_{10}	Replacing old line locomotive and requiring new locomotives to meet US Tier 4	208,722	104,361	50%
PM_{10}	Mandatory low sulfur fuel use by ships while at berth	93,618	46,809	50%
PM_{10}	MOU to reduce shipping vessel speed for ocean transits	19,881	9,940	50%
PM_{10}	Diesel retrofit at mine sites (ERP)	31,341	31,341	No adjustment
PM_{10}	Adoption of international best practice PM control measures at coal mines	3,637	3,637	No adjustment
PM_{10}	Retrofitting high-polluting (urban) diesel engines & equipment with DPFs	44,281	44,281	No adjustment
PM_{10}	Open cut coal mines - buffer zone initiative	-	-	No adjustment
PM_{10}	Refinery Vapour Recovery and Leak Detection and Repair	1,863	1,863	No adjustment
Nitrogen	Constructed wetlands - South Creek, NSW (2002)-Urban	12,184	12,184	No adjustment
Nitrogen	Constructed wetlands - Port Phillip Bay, VIC-Urban	97,472	97,472	No adjustment

Pollutant	Measure	Based on original study estimate ($/t)	Estimate after cost allocation ($/t)	Adjustment
Nitrogen	Constructed wetlands - Port Waterways, SA -Urban	73,104	73,104	No adjustment
Nitrogen	Better treatment at STPs - Port Phillip Bay, VIC-Urban	60,920	60,920	No adjustment
Nitrogen	Better treatment at STPs - Port Waterways, SA -Urban	243,681	243,681	No adjustment
Nitrogen	Other point sources - Port Waterways, SA -Urban	14,621	14,621	No adjustment
Nitrogen	Modifying fertilizer use by horticulture - South Creek, NSW (2002)-Agricultural	6,092	6,092	No adjustment
Nitrogen	Modifying fertilizer use by horticulture - Port Phillip Bay, VIC-Agricultural	6,092	6,092	No adjustment
Nitrogen	Riparian restoration - South Creek, NSW (2002)-Agricultural	12,184	12,184	No adjustment
Nitrogen	Riparian restoration - Port Waterways, SA -Agricultural	6,092	6,092	No adjustment
Nitrogen	Buffer strips on horticultural land - South Creek, NSW (2002)-Agricultural	18,276	18,276	No adjustment
Nitrogen	Best practice for cropping - Port Phillip Bay, VIC-Agricultural	67,012	67,012	No adjustment
Nitrogen	Best practice for cropping - Port Phillip Bay, VIC-Agricultural	67,012	67,012	No adjustment
Nitrogen	Advanced denitrification MLE 40% anoxic-Castle Hill STP	6,092	6,092	No adjustment
Nitrogen	Pushed dentrification MLE 40% anoxic - West Camden STP	7,310	7,310	No adjustment
Nitrogen	Enhanced denitrification add fermentation-Wimnmalee STP	14,621	14,621	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-St Marys STP	21,931	21,931	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-Quakers Hill STP	21,931	21,931	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-Riverstone STP	21,931	21,931	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-Rouse Hill STP	25,586	25,586	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-West Hornsby STP	25,586	25,586	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-Hornsby heights STP	30,460	30,460	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-North Richmond STP	40,207	40,207	No adjustment
Nitrogen	Benchmark N removal Bardenpho II Methanol dosing-Richmond STP	40,207	40,207	No adjustment
Nitrogen	Market garden - runoff reuse-Agricultural	121,840	60,920	50%
Nitrogen	Market garden - settlement pond-Agricultural	30,460	15,230	50%
Nitrogen	Greenhouse - wetland and recycling-Agricultural	121,840	60,920	50%
Nitrogen	Greenhouse & vegetable garden - runoff reuse-Agricultural	97,472	48,736	50%
Nitrogen	Compost study at market garden-Agricultural	127,932	63,966	50%
Nitrogen	Fence/alternative water supply on grazing land-Agricultural	536,097	268,049	50%
Nitrogen	Biological nutrient removal - Low (small STP)-SEQ	18,584	18,584	No adjustment
Nitrogen	Biological nutrient removal - High (large STP)-SEQ	696	696	No adjustment
Nitrogen	Nutrient removal from a hay and sorghum rotation -Small area-SEQ	10,951	10,951	No adjustment

Pollutant	Measure	Based on original study estimate ($/t)	Estimate after cost allocation ($/t)	Adjustment
Nitrogen	Nutrient removal from a hay and sorghum rotation - Large area-SEQ	3,021	3,021	No adjustment
Nitrogen	Fencing and Riparian Revegetation - Grazing-SEQ	9,461	9,461	No adjustment
Nitrogen	Fencing and Riparian Revegetation - Intensive ag.-SEQ	3,784	3,784	No adjustment
Nitrogen	Nutrient removal from a pine pulpwood plantation - Small area-SEQ	70,468	70,468	No adjustment
Nitrogen	Nutrient removal from a pine pulpwood plantation - Large area-SEQ	35,416	35,416	No adjustment
Nitrogen	Tertiary filtration - Low (small STP)-SEQ	195,139	195,139	No adjustment
Nitrogen	Tertiary filtration - High(large STP)-SEQ	81,309	81,309	No adjustment
Phosphorus	P Polishing Contact filtration-Wimnmalee STP	269,267	269,267	No adjustment
Phosphorus	P Polishing Contact filtration-Rouse Hill STP	341,153	341,153	No adjustment
Phosphorus	P Polishing Contact filtration-Castle Hill STP	341,153	341,153	No adjustment
Phosphorus	Benchmark P removal Tertiary clarification-St Marys STP	721,295	721,295	No adjustment
Phosphorus	Benchmark P removal Tertiary clarification-Quakers Hill STP	721,295	721,295	No adjustment
Phosphorus	Benchmark P removal Tertiary clarification-West Camden STP	977,159	977,159	No adjustment
Phosphorus	Market garden - runoff reuse-Agricultural	901,618	450,809	50%
Phosphorus	Market garden - settlement pond-Agricultural	268,049	134,024	50%
Phosphorus	Greenhouse - wetland and recycling-Agricultural	481,269	240,635	50%
Phosphorus	Greenhouse & vegetable garden - runoff reuse-Agricultural	694,490	347,245	50%
Phosphorus	Compost study at market garden-Agricultural	804,146	402,073	50%
Phosphorus	Fence/alternative water supply on grazing land-Agricultural	42,644	21,322	50%
Phosphorus	Biological nutrient removal - Low (small STP)-SEQ	24,779	24,779	No adjustment
Phosphorus	Biological nutrient removal - High (large STP)-SEQ	783	783	No adjustment
Phosphorus	Eucalypt sawlog plantation - Small area-SEQ	463,517	463,517	No adjustment
Phosphorus	Eucalypt sawlog plantation - Large area-SEQ	123,790	123,790	No adjustment
Phosphorus	Fencing and Riparian Revegetation - Grazing-SEQ	76,526	76,526	No adjustment
Phosphorus	Fencing and Riparian Revegetation - Intensive ag.-SEQ	51,131	51,131	No adjustment
Phosphorus	Tertiary filtration - Low (small STP)-SEQ	18,295	18,295	No adjustment
Phosphorus	Tertiary filtration - High(large STP)-SEQ	15,245	15,245	No adjustment
Phosphorus	Precipitation - activated sludge effluent to 2mg/L - Low (small plant w sludge mgmt and disposal)-SEQ	5,194	5,194	No adjustment
Phosphorus	Precipitation - activated sludge effluent to 2mg/L - High (large plant w sludge mgmt)-SEQ	2,775	2,775	No adjustment
Phosphorus	Precipitation - BNR effluent to 0.25 - 0.5 mg/L - Low (Small plant w sludge mgmt and disposal)-SEQ	8,161	8,161	No adjustment
Phosphorus	Precipitation - BNR effluent to 0.25 - 0.5 mg/L - High (Large plant w sludge mgmt)-SEQ	3,739	3,739	No adjustment

Pollutant	Measure	Based on original study estimate ($/t)	Estimate after cost allocation ($/t)	Adjustment
Phosphorus	WSUD - Swales - (high) - Assumed maximum cost effectiveness-Greater Brisbane	32,185	32,185	No adjustment

Appendix F Case Study 1 – SCR for NO_X emissions on NSW Coal Power Stations

Overview

This case study considers the potential for the adoption of selective catalytic reduction (SCR) technology on coal powered electricity generation in NSW. Discussions with the industry indicate that SCR is not currently used at any of the coal-fired power stations in NSW. No other NOx-reduction measures are currently in use, although the modification of the combustion process is being considered at some facilities.

SCR systems catalytically reduce flue gas NO_X to nitrogen and water. The NO_X reduction takes place as the flue gas passes through a catalyst chamber. Before entering the catalyst, ammonium or urea solution as the reagent is injected into the flue gas.

SCR is a well-proven technology for large industrial applications. It has been used commercially in Japan since 1980 and in Germany since 1986 on power stations burning low-sulfur and medium-sulfur coal. SCR is deployed in approximately 30 per cent of US coal plant[7].

Profile of emissions from activity

The generation of electrical power from coal was estimated to emit a total of **130,110** tonnes of NO_X from licenced facilities in NSW in financial year 2012/13. These includes:

- **Some** licenced facilities located in a region where a critical zone weighting of 2 applies (within local government areas Cessnock City, Gosford City, Lake Macquarie City, Maitland City, Muswellbrook, Newcastle City, Port Stephens, Singleton, Wollondilly, Wyong);
- **No** licenced facilities located in a region where a critical zone weighted of 7 applies (within local government areas in the Sydney basin area, Blue Mountains City, Kiama, Shellharbour City and Wollongong City) and
- **Some** licenced facilities in other local government areas in NSW (where there is no critical zone weighting applied).

Estimate of potential emissions reduction from adopting SCR in NSW

Typical NO_X removal with SCR ranges from 50 to 90 per cent, reflecting the range of systems and operational configurations in use. The literature indicates that a removal efficiency of greater than 80 per cent ought to be achievable for a modern SCR system at a coal-fired power station (IEA-CCC, November 2009). NO_X removal can be greater than 90 per cent, but this requires a tightly controlled supply of reagent and tends not to be cost-effective (USEPA, 2003; Moretti & Jones, 2012). There are also concerns about the overall economic feasibility of SCR within the industry in NSW. For this case study we have assumed a NO_X removal efficiency from SCR of 80 per cent, which is probably a conservative estimate. An 80 per cent reduction would equate to a **104,088** tonne reduction from licensed facilities.

[7] http://www.nma.org/pdf/fact_sheets/cct.pdf

Estimate of the cost, financial and social benefits of adopting SCR in NSW

Adopting SCR technology on coal fired power stations would result in:

- An incremental financial cost incurred by each coal fired power station to install and operate the technology;
- A financial benefit to coal fired power stations through avoided Load Based Licence (LBL) fees paid by facilities; and
- Wider community benefits (reduced health costs and environmental damage due to reduced pollution).

Financial costs and benefits are referred to as ‘private’ costs and benefits as they are directly incurred by the party undertaking the project. Wider community costs and benefits are referred to as ‘social’ costs and benefits. These impacts have been derived from the comparison of abatement costs, external costs and LBL fees, and are compared in Table F1 below.

Table F1 **Impacts of adopting SCR on NSW coal power stations**

	Private Costs	Private Benefits	Community Benefits
	Installation and operation costs	**Reduced LBL fees**	**Reduced environmental and social harm from NO_X**
Annualised	$91.7m per year (includes annual operating expenditure and annualised cost of capital upgrades)	$6.9m per year in avoided LBL fees	$175.6m per year (using a median value from a range of local and international estimates of the damage caused by NO_X to the community)
Dollars per tonne of NO_X	$881 per tonne of NO_X (estimate from literature)	$66 per tonne of NO_X (average paid by licensees)	$1,687 per tonne of NO_X (median value from literature)

The average fees paid by licences ($66 per tonne) takes into account that the base fee rate applying to facilities in local government areas with a zone weighting of 2 is $83 per tonne, the base fee rate applying to facilities in local government areas with a zone weighting of 1 is $41 per tonne and that some of the facilities pay higher than the base rate because they exceed a certain ‘fee rate threshold’ set by the NSW EPA where twice the base rates apply for excess emissions.

The level of the fee alone would not be a strong financial motivator for industry to install SCR (costs of which are estimated to be $881 tonne). Using a median estimate of the damage caused by NO_X to the community, if SCR were adopted, there could be approximately $175m per year in community benefits. However, estimates of this avoided damage cost (or community benefit) vary widely and are uncertain. A detailed cost benefit analysis would need to be undertaken to more precisely assess the costs and benefits.

Appendix G Case Study 2 – Biologically active filters and denitrifying filters with methanol dosing at Bega Valley's Merimbula Sewage Treatment Plant (STP)

Overview

In March 2011, Bega Shire Council established a focus group to provide advice on effluent management strategies for the Merimbula Sewage Treatment Plant (STP). The consideration of effluent management options was driven by climate change concerns, the availability of new treatment technologies, and a desire to reduce environmental impacts.

The focus group compared various options for the disposal system (the way effluent is discharged), reuse (using the water for another purpose) and STP upgrades (to treat effluent from the STP prior to discharge).

One of the upgrade options considered was the use of biologically active filters (BAFs) and denitrifying filters with methanol dosing. These would be placed downstream of the effluent storage pond, and would convert organic nitrogen and ammonium to nitrogen gas through a two-step process.

In the first step the effluent is passed under gravity through the BAFs. These consist of a granular bed, usually of vitrified clay particles. Constant aeration results in aerobic biological growth and nitrification, with ammonium being sequentially oxidised to nitrite and then to nitrate.

The second step involves the denitrification of the effluent, whereby the nitrates are reduced to gaseous nitrogen. The denitrification filters consist of a medium which supports the growth of anaerobes which promote the conversion of nitrates to nitrogen gas. A biodegradable organic compound - usually methanol - must be available to facilitate the conversion. Methanol storage and dosing facilities must therefore accompany the denitrification filter.

Profile of emissions from STP

Load-based licencing data for the Merimbula facility are publicly available from the licence search facility on the NSW EPA website (http://www.epa.nsw.gov.au/prpoeoapp/). Table G1 below shows the facility's assessable load and pollutant fees, based on the latest year of data available for the Merimbula STP (financial year 2012/13).

Table G1 **Merimbula STP Assessable load and pollutant fees (2012/13)**

	Discharges to Coastal Water		Discharges to Enclosed Water	
	Assessable Load	**Pollutant Fee**	**Assessable Load**	**Pollutant Fee**
Nitrogen	1,552	$40	1,421	$139
Phosphorus	2,648	$-	2,425	$13,792
Biochemical oxygen demand (BOD)	1,365	$-	1,249	$5
Oil and Grease	604	$35	553	$174
Total suspended solids (TSS)	2,953	$120	2,704	$899

Estimate of potential emissions reduction from adopting biologically active filters and denitrifying filters with methanol dosing at Merimbula STP

Five case studies involving the use of methanol in wastewater denitrification were presented by Exponent (2012). The case studies for separate-stage processes indicated removal efficiencies for total nitrogen of between 40 and 90 per cent, although the value was estimated to be greater than 85% for three of the case studies. Given the uncertainty, in our case study we have used a mid-range estimate of 65%, equating to a **1,933 kg** reduction in nitrogen discharge from the STP.

There appears to be little information on the removal efficiency for other contaminants, and this will depend on the technology used. Phosphorus is typically bound to suspended solids, and a physical filter may remove these. However, given the uncertainty in the removal efficiency we have undertaken our analysis using a lower bound value of 20% and an upper bound value of 80%. Given that the Merimbula STP denitrification system will include tertiary filtration for more efficient removal of phosphorus, it is possible that the removal efficiency will be closer to the higher end of the range.

Estimate of the cost, financial and social benefits of adopting biologically active filters and denitrifying filters with methanol dosing at Merimbula STP

A review of the costs of various STP plant upgrades, including removal of nitrogen from effluent through methanol dosing, yielded a very wide range of cost estimates (ranging from approximately $1,000 per tonne of nitrogen to approximately $200,000 per tonne of nitrogen). However, "fact sheets" published by the Council on its website[8] provide figures that enable a more specific estimation.

The data from the fact sheets, data on emission reductions, and data on emissions liability were used to compare the private and social costs and benefits that could result from this measure. These are shown in Table G2.

While international estimates of the damage cost of nitrogen and phosphorus were available (Danish Ministry for the Environment, 2005), there was no available estimate of the damage cost of total suspended solids (TSS). In their report on a proposed licence fee system for South Australia, BDA Group (2006) ranked air and water pollutants on a logarithmic scale based on an assessment of relative harm. In that assessment nitrogen, phosphorus and

8 http://www.begavalley.nsw.gov.au/cp_themes/default/page.asp?p=DOC-TNF-05-80-61

TSS were assigned the same pollutant weight. Therefore the following assumptions for damage costs of water pollutants were adopted:

- A damage cost assumption of $15,300 per tonne of nitrogen using a mid-point estimate from a single international study (no Australian estimates were available);
- A damage cost assumption of $74,000 per tonne of phosphorus using a mid-point estimate from a single international study (no Australian estimates were available);
- A damage cost assumption of $15,300 per tonne of TSS (to be applied with the 'lower bound' sensitivity test assuming 20% reduction in phosphorus and TSS); and
- A damage cost assumption of $74,000 per tonne of TSS (to be applied with the 'upper bound' sensitivity test assuming 80% reduction in phosphorus and TSS);

Table G2 **Impacts of adopting Biologically Active Filters and De-Nitrifying Filters with Methanol Dosing at Merimbula STP (lower bound sensitivity)**

Private Costs	Private Benefits	Community Costs	Community Benefits
Installation and operation costs	**Reduced LBL fees**	**Release of Greenhouse Gas (GHG) emissions**	**Reduced environmental and social harm**
$520,729 per year (includes annual operating expenditure and annualised cost of capital upgrades)	Nitrogen $116 per year Phosphorus $2,758 per year TSS $204 per year Total $3,078 per year	$316 (assuming $30 per tonne of CO_2)	Nitrogen $29,573 per year (mid-point estimate from international study) Phosphorus $75,082 per year (mid-point estimate from international study) TSS $17,310 per year (mid-point estimate from international study) Total $121,965 per year

Table G3 **Impacts of adopting Biologically Active Filters and De-Nitrifying Filters with Methanol Dosing at Merimbula STP (upper bound sensitivity)**

Private Costs	Private Benefits	Community Costs	Community Benefits
Installation and operation costs	**Reduced LBL fees**	**Release of Greenhouse Gas (GHG) emissions**	**Reduced environmental and social harm**
$520,729 per year (includes annual operating expenditure and annualised cost of capital upgrades)	Nitrogen $116 per year Phosphorus $11,033 per year TSS $815 per year Total $11,964 per year	$316 (assuming $30 per tonne of CO_2)	Nitrogen $29,573 per year (mid-point estimate from international study) Phosphorus $300,328 per year (mid-point estimate from international study) TSS $334,888 per year (mid-point estimate from international study) Total $664,789 per year

In the lower bound sensitivity, the annual cost of the measure exceeds community benefits. However, in the upper bound sensitivity, the measure is closer to ‘breakeven’ on an economic basis, delivering community benefits in excess of project costs.

There is significant uncertainty surrounding assumptions, particularly in the absence of available Australian damage cost estimates for water pollutants and uncertain removal efficiency of phosphorus and TSS.